Communications System Architecture Development For Air Traffic Management & Aviation Weather Information Dissemination

Research Task Order 24

Subtask 4.6, Develop AATT 2015 Architecture

(Task 5.0)

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Submitted to
NASA Glenn Research Center
under
Contract NAS2-98002

May, 2000

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1 Executive Summary

1.1 Background

The Advanced Air Transportation Technologies (AATT) initiative has a number of project sub-elements ranging from advanced ATM concept development to aircraft systems and operations. It also has an Advanced Communications for Air Traffic Management (AC/ATM) task with a goal of enabling an aeronautical communications infrastructure through satellite communications that provides the capacity, efficiency, and flexibility necessary to realize the benefits of the future ATM system and the mature Free-Flight environment. Specifically, the AC/ATM task is leveraging and developing advanced satellite communications technology to enable Free Flight and provide global connectivity to all aircraft in a global aviation information network. The task directly addresses the Office of Aerospace Technology (OAT) Enterprise Pillar One Enabling Technology Goal of increasing aviation throughput as part of the AATT Project. The objectives of the AC/ATM task are to:

1. Identify the current communication shortfalls of the present ATM system
2. Define communications systems requirements for the emerging AATT concept(s)
3. Demonstrate AATT concepts and hardware
4. Develop select high-risk, high payoff advanced communications technologies.

The technical focus of the AC/ATM task has centered on the development of advanced satellite communications technology as a select high-risk, high payoff technology area in support of ATM communications (objective 4 above). Although the thrust of the task has been satellite communications (SATCOM), aeronautical air-ground communications will be provided for the foreseeable future by a number of different communications systems/data links, including HF, VHF, L-band, and SATCOM. Relevant advanced technology development for any of these systems requires that a comprehensive technical communications architecture exist. In satisfaction of objectives 1 and 2, a comprehensive technical communications system architecture must be defined and developed. That architecture must address the user communications requirements of the future mature ATM system that the various data links mentioned can support.

1.2 Objectives

The objective of Task 5 is to develop a 2015 AATT Communication System Architecture; i.e., to develop a Communication System Architecture (CSA) with the potential for implementation by 2015. This CSA is to be comprehensive and driven by derived communications system engineering requirements. It must include a detailed technical description of all communications/data links required by the 2015 architecture, including all air-ground and air-air links, with each required communications/data link defined with respect to its end-to-end link characteristics. The CSA must provide a definition of the network, standards, and protocol requirements for the overall architecture and for each data link. It must identify and provide mitigating solutions for any unique implications to the ground-ground communication network infrastructure in realizing or implementing the identified air-air and air-ground data links.

1.3 Technical Approach

The specific Task 5 objective of developing a 2015 AATT Communication System Architecture must be viewed within the context of the overall National Airspace System (NAS) and the services it provides. For example, NASA's Office of Aerospace Technology has identified a technology objective stating:

While maintaining safety, triple the aviation system throughput, in all weather conditions, within 10 years.

This objective clearly indicates the need to view the CSA in the full context of the NAS and, in particular, the Air Traffic Management (ATM) component of the NAS. To provide that context, we extracted user needs and high-level goals (Task 1) from multiple sources, including other NASA and FAA programs, RTCA activities, and industry. From these needs and goals, we developed a consensus vision and concept of operations for the 2015 architecture to provide a "top down" perspective. We further refined the operational concept into nine communication technical concepts that formed our functional communication architecture.

The functional communication architecture was used to formulate alternative technology solutions for the physical architecture based on the results of our communication loading analysis (Section 4) and our determination of communication link capabilities (Section 5). This process is illustrated in Panel A of Figure 1.3-1.

Concurrent with the process of defining technology alternatives for the 2015 AATT communication system architecture, we reviewed the current NAS Architecture plans to develop a "bottom up" perspective of what systems and capabilities are expected to be in place in 2015. With this "projected" definition, we were able to compare the 2015 AATT CSA technology alternatives to the bottom-up view 2015 NAS Architecture to identify the differences (or "gaps") between the two and to develop a 2015 AATT Architecture. This process is illustrated in Panel B of Figure 1.3-1. Task 10 and Task 11 will identify the gaps more comprehensively and make recommendations on areas of research or development to close them. These tasks, along with the Transition Plan task (Task 8), also will define an effective transition path from today's NAS Architecture, through a 2007 Architecture (Task 6) and the 2007 AWIN Architecture (Task 7), to the 2015 AATT CSA.

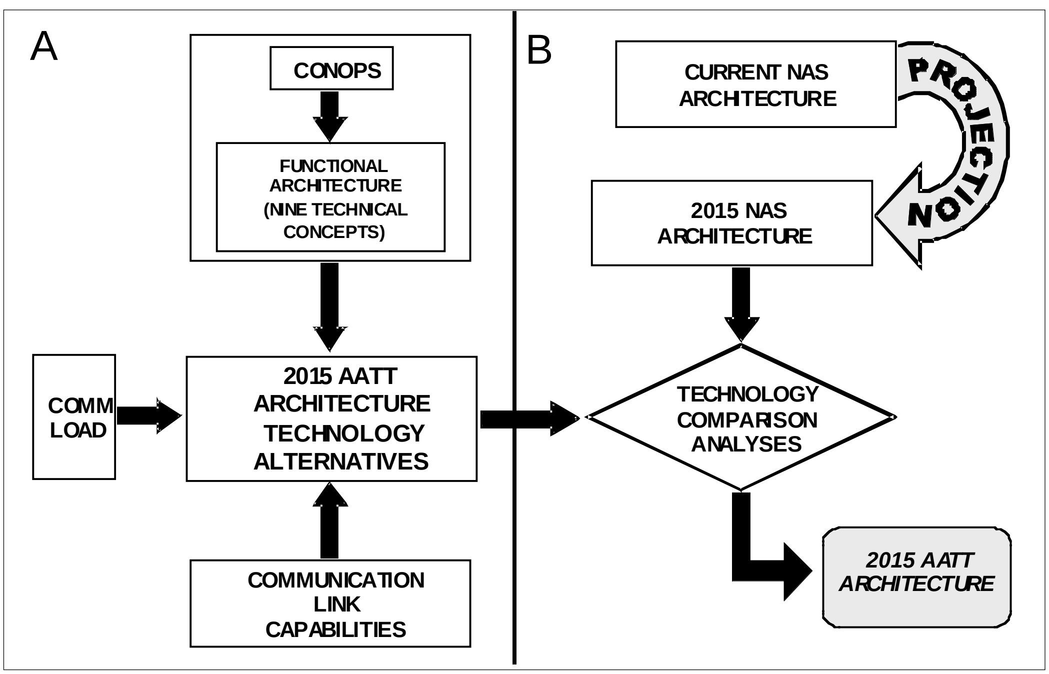

Figure 1.3-1. 2015 AATT Architecture Development Method

1.4 Results of This Task

The 2015 time frame represents the final phases of transition from the era of analog voice communication and islands of diverse information to the new era of digital data exchange through integrated networks using common data. The results of this transition are an integrated collection of systems and procedures that efficiently use the capacity of the NAS while balancing access to all user classes and maintaining the highest levels of safety. As depicted in Figure 1.4-1, efficient collaboration among users is built on a foundation of common data that composes the information base. This data can be logically divided into a static component, representing data that changes infrequently such as maps, charts, etc., and a dynamic component, representing data that changes frequently such as the weather, traffic flow status, and aircraft position. This information base provides common situational awareness to all users who choose to participate. In this time frame, there a variety of users who will choose to participate at various levels of equipage ranging from voice only through multi-mode radios and fully modular avionics. All users are accommodated, however, and will receive benefits commensurate with their levels of equipage.

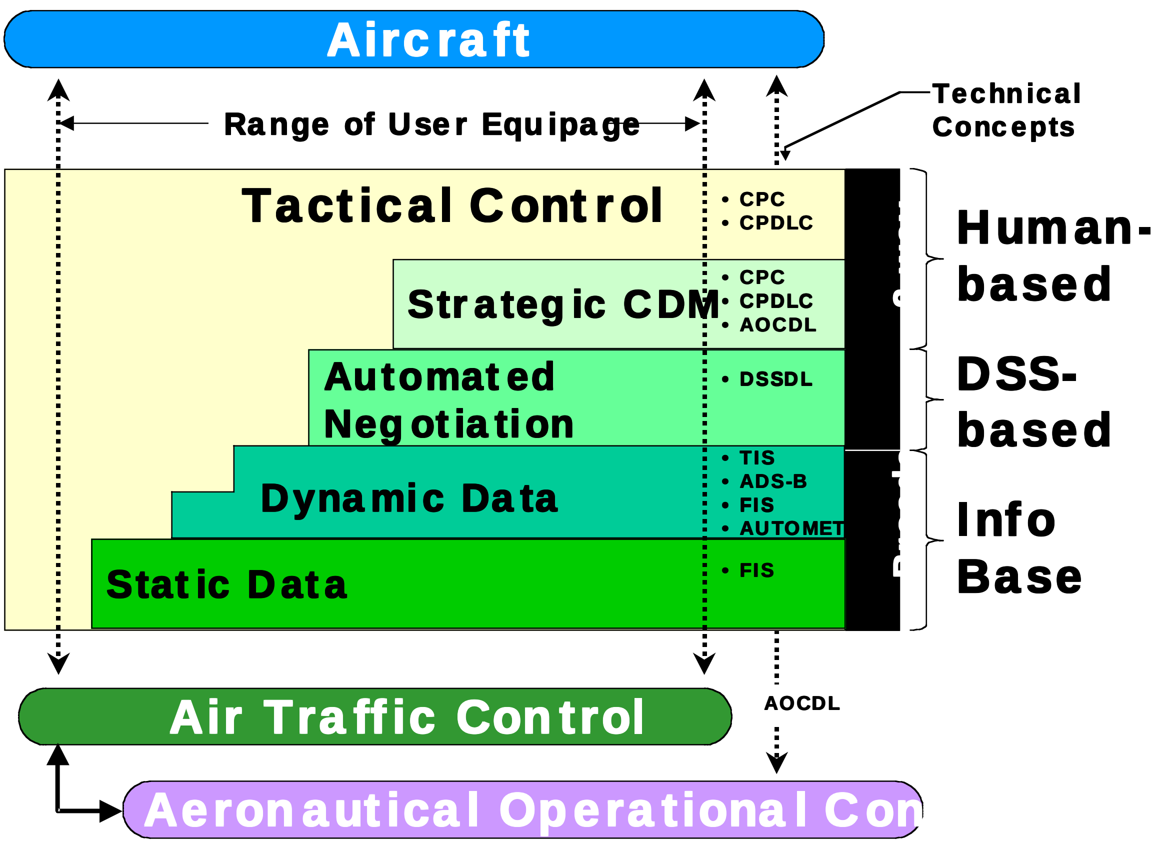

Figure 1.4-1. Air-Ground Communication Levels

The challenge in maintaining the information base is to keep the dynamic data current for all participating users so that optimum decisions can be made. Given a common information base, decision support systems can analyze this data continuously to develop optimum solutions for individual aircraft trajectories as well as trajectories for groups of aircraft. This negotiation takes place between aircraft Decision Support System (DSS) tools and between aircraft and ATC DSS tools. When optimum solutions (or inability to find a solution) are determined, pilots and controllers are notified for confirmation (or other appropriate action). This action takes the form of strategic collaborative decision making or tactical control. In either event, data exchange continues using specified data link messages with voice communication used when it is the only practical means.

Our analysis of user needs and the latest concepts of operation led us to define these levels of air-ground communication and to also define a collection of technical communication concepts for categorizing the various levels of data exchange that we discovered. These technical concepts are defined in Table 1.4-1 and also are highlighted within their applicable levels in Figure 1.4-1. A more detailed explanation of each technical concept can be found in Section 3 of this report.

The combinations of these technical concepts form the functional communications architecture shown in Figure 1.4-2. Our use of the NAS-Wide Information System (NWIS) at the center of the functional architecture represents a key assumption in performing this analysis. In the 2015 time frame, the ground-side NAS has evolved to the point that it contains a collection of data that is commonly defined and virtually available among all participating nodes using the most efficient communications paths available. Additionally, each participating node – either airborne or ground – has sufficient processing and storage capability that these capabilities will not be limiting factors in the timely exchange of information between nodes.

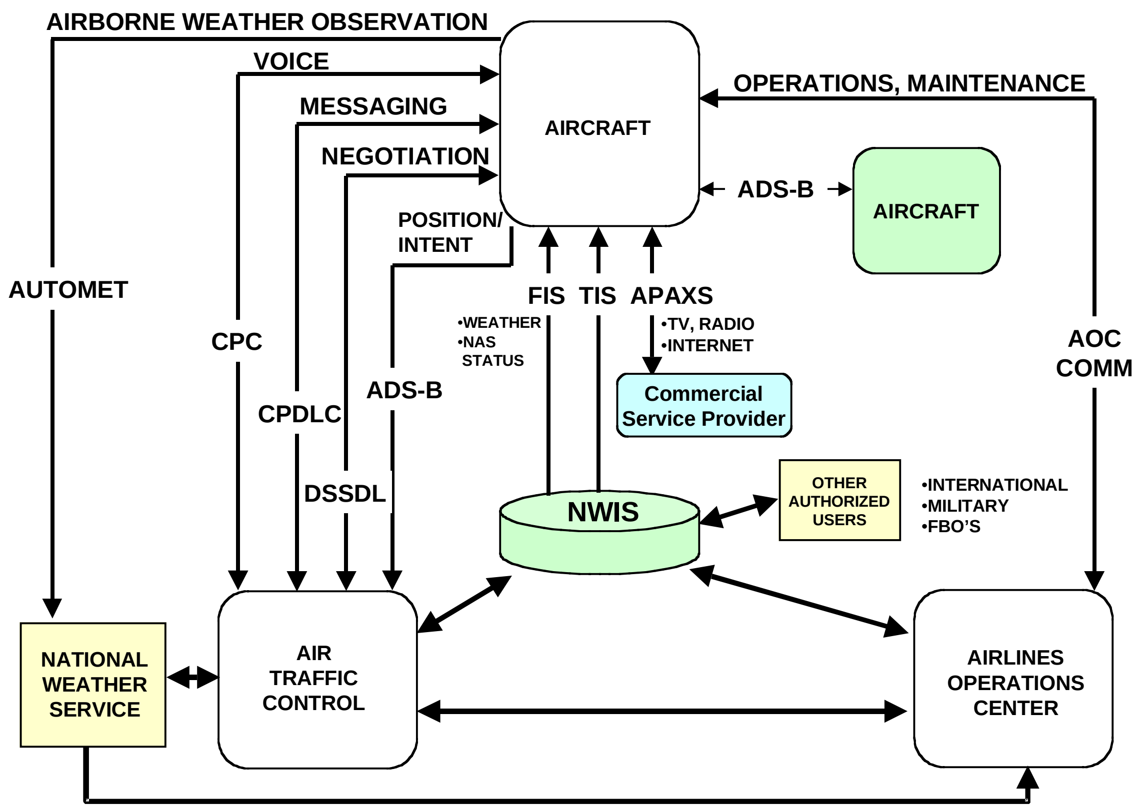

Figure 1.4-2. 2015 AATT Functional Communication System Architecture

The transformation of the functional architecture into a physical architecture was accomplished by comparing the message load requirements for each functional interface (Section 4) with the capabilities of the enabling communications links (Section 5).

Table 1.4-1. 2015 Technical Concepts

Technical Concept Definition	Technical Concept Name
Aircraft continually receive Flight Information to enable common situational awareness	Flight Information Services (FIS)
Aircraft continually receive Traffic Information to enable common situational awareness	Traffic Information Services (TIS)
Controller - Pilot voice communication	Controller - Pilot Communication (CPC)
Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories (including Hazardous Weather Alerts)	Controller-Pilot Data Link Communications (CPDLC)
Aircraft exchange performance / preference data with ATC to optimize decision support	Decision Support System Data Link (DSSDL)
Aircraft continuously broadcast data on their position and intent to enable optimum maneuvering	Automated Dependent Surveillance-Broadcast (ADS-B)
Pilot - AOC messaging supports efficient air carrier/air transport operations and maintenance	Airline Operational Control Data Link (AOCDL)
Aircraft report airborne weather data to improve weather nowcasting/forecasting	Automated Meteorological Transmission (AUTOMET)
Commercial service providers supply in-flight television, radio, telephone, entertainment, and internet service	Aeronautical Passenger Services (APAXS)

We determined the functional interface loading by logically grouping the message requirements that were identified in Tasks 1, 2, and 3 of this Task Order. We recognized, however, that the air-ground exchange of data would not be the same for all aircraft. We therefore chose to use three classes of aircraft: low-end general aviation (Class 1), high-end general aviation and commuter aircraft (Class 2), and commercial carriers (Class 3). These classifications lead to a better traffic load estimate since the number, frequency, and type of message in many cases depends on where the aircraft is and what type of equipage it has. Additionally, we chose to partition the analysis by domain so that the air-ground communication architecture could be optimized to meet any special regional requirements. A summary of the peak communication loads for 2015 is provided in Table 1.4-2.

Table 1.4-2. Summary of Peak Communication Loads for 2015 (kbps)

Data Message Traffic for All Classes of Aircraft (K-bits per second)						
2015	**Airport Uplink**	**Airport Downlink**	**Terminal Uplink**	**Terminal Downlink**	**En Route Uplink**	**En Route Downlink**
FIS	0.2	0.0	0.9	0.0	6.9	0.0
TIS	23.7	0.0	7.0	0.0	20.5	0.0
CPDLC	3.4	2.9	1.3	0.9	1.1	1.3
DSSDL	0.2	0.3	0.1	0.2	0.1	0.1
AOC	0.4	8.4	0.6	8.5	0.2	3.5
ADS Reporting	0.0	16.1	0.0	3.3	0.0	1.5
AUTOMET	0.0	0.0	0.0	4.4	0.0	6.2
APAXS	0.0	0.0	0.0	0.0	131.7	115.5

As mentioned previously, the NAS in 2015 requires a data exchange capability that supports the establishment of an air-ground information base. The technical concepts that support this information base are FIS, TIS, ADS-B, and AUTOMET. Taken individually, a solution for each of these concepts could be developed from one of the individual links identified in Table 1.4-3. When viewed from a systems perspective, however, the notion of an integrated data exchange capability begins to emerge. Candidate links that could meet this integrated data exchange need should be capable of supporting data rates on the order of hundreds of kilobits per second.

Table 1.4-3. Capacity Provided by Various Communication Links

Data Link	Single Channel Data Rate	Capacity for Aeronautical Communications	Channels Available to Aircraft	# Aircraft Sharing Channel (Expected Maximum)	Comments
	kbps	Channels	Channels	Aircraft	
HFDL	1.8	2	1	50	Intended for Oceanic
ACARS	2.4	10	1	25	ACARS should be in decline as users transition to VDL Mode 2
VDL Mode 2	31.5	4+	1	150	System can expand indefinitely as user demand grows
VDL Mode 3	31.5*	~300	1	60	Assumes NEXCOM will deploy to all phases of flight
VDL Mode 4	19.2	1-2	1	500	Intended for surveillance
VDL – B	31.5	2	1	Broadcast	Intended for FIS
Mode-S	1000**	1	1	500	Intended for surveillance
UAT	1000	1	1	500	Intended for surveillance/FIS
SATCOM	-	-	-	-	Assumes satellites past service life
Future SATCOM	384	15	1	~200	Planned future satellite
Future Ka Satellite	2,000	~50	~50	~200	Estimated capability - assumes capacity split for satellite beams
Fourth Generation Satellite	>100,000	>100	>100	Unknown	Based on frequency license filings

* Channel split between voice and data.
** The Mode-S data link is limited to a secondary, non-interference basis with the surveillance function and has a capacity of 300 bps per aircraft in track per sensor (RTCA/DO-237).

In addition to data exchange, the NAS also requires a two-way data messaging capability to support the efficient coordination of information, decision making, and the delivery of clearances and advisories. The technical concepts that support this are AOCDL, DSSDL, and CPDLC. Candidate links that could meet these needs should be ATN compliant and capable of supporting data rates on the order of tens of kilobits per second.

A summary of the applicable communication links that we project will be capable of supporting the communication loads for each technical concept is provided in Table 1.4-4.

Table 1.4-4 2015 AATT Technical Concepts to Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Aircraft continuously receive Flight Information to enable common situational awareness	**FIS**					✓		✓	✓	
Aircraft continuously receive Traffic Information to enable common situational awareness	**TIS**					✓		✓	✓	
Controller - Pilot Communication	**CPC**	✓		✓						
Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories (including Hazardous Weather Alerts)	**CPDLC**			✓						
Aircraft exchange performance / preference data with ATC to optimize decision support	**DSSDL**			✓						
Aircraft continously broadcast their position and intent to enable optimum maneuvering	**ADS-B**				✓		✓	✓		
Pilot - AOC data exchange supports efficient air carrier/air transport operations and maintenance	**AOCDL**		✓					✓		✓
Aircraft report airborne weather to improve weather nowcasting/forecasting	**AUTOMET**		✓					✓		✓
Passengers enjoy in-flight television, radio, telephone, and internet service	**APAXS**								✓	✓
✓ Acceptable Alternative		NAS Architecture		AATT CSA Recommendation						

From an integrated NAS Architecture perspective, we feel that an attempt should be made to minimize the number of aircraft radios required to operate efficiently while recognizing the desirability of maintaining a level of robustness across CNS avionics. With this in mind, our optimum aircraft would have a multimode VHF radio to support two-way messaging, a broadband UAT or SATCOM radio to support data exchange, a Mode-S radio to support surveillance and collision avoidance, and finally a radio to support navigation. (Note: surveillance and navigation analysis were not considered within the scope of this analysis).

For CPC, CPDLC, and DSSDL, our recommendation follows that of the NAS Architecture. The implementation of VDL-3 will more than adequately accommodate the ATC needs of 2015 and beyond. The transition to VDL-3 could be problematic, however, given the load projections for the VDL-2 network. There will continue to be a need to maximize the communication capacity of VHF data links operating in the protected aviation spectrum. Accordingly, we recommend further research in the areas of link modulation and data compression to increase the overall bit transfer rate, network prioritization schemes that combine voice and data, and the development of designs for virtual air ground links that will maximize the use of available frequencies.

We have not made a recommendation for FIS, TIS, or ADS-B, because we feel that there is additional research required to provide sufficient data to support a recommendation. An integrated data exchange capability as we discuss in this analysis is not currently envisioned in the NAS Architecture. Additionally, the link decision currently underway on ADS-B can have a significant influence on the overall communication system architecture. With regard to the implementation of UAT or SATCOM, one potential advantage of using UAT would be that the majority of aircraft would already have a UAT radio [if it is (one of) the technology (ies) chosen for ADS-B] and a UAT terrestrial network would have been established. Additionally, UAT avionics have been designed to support all classes of aircraft. Implementation of UAT should consider the use of dedicated channels and protocols for ADS-B and TIS to optimize their performance, while FIS and AUTOMET could employ a more standard broadcast scheme. An advantage of SATCOM would be the wide area access provided without the need for a terrestrial network and the use of a commercial service provider. A current disadvantage for next genration SATCOM, however, is that antennas and receivers must be adapted for the aviation market (size, weight, cost) and must overcome the condition of rain attenuation for broadcast.

We have not made a recommendation for AOCDL because it is a commercial link. The current plans for implementation of AOCDL is via VDL-2 using four allocated AOC frequencies. Costs for two-way SATCOM service may be attractive for the AOCs if it is coupled with some form of APAXS that make it cost competitive with VDL-2.

AUTOMET is problematic in that our load projections exceed any VDL solutions. However, in all likelihood, AUTOMET will begin on the AOCDL VDL-2 network in the 2007 time frame. If an integrated data exchange capability is developed as described above, we would recommend it for AUTOMET. Absent that, we recommend that AUTOMET continue to use the same link as AOCDL (VDL-2 or SATCOM).

Finally, for APAXS, the use of SATCOM will be driven by the commercial industry desire to provide high-data-rate services to passengers such as real time television and Internet access. These services are already available to private executive and business aircraft. Air Traffic Service providers should stay aware of these efforts and look for opportunities to exploit this method of data transmission. Accordingly, we recommend that further study be conducted to determine the possibility for innovative partnerships or incentives that may leverage the involvement of commercial service providers in the delivery of selected air traffic services via SATCOM. For example, providers of broadcast entertainment channels to aircraft could be required to provide an air traffic services channel that is freely accessible by all aircraft. This example is similar to the requirement that cable television providers have with regard to providing public access channels.

In summary, for the 2015 time frame, a majority of Class 1 aircraft are equipped with a VHF multimode radio for voice and data communications and ADS-B avionics that transmit their derived position via the selected link (Mode-S, VDL-4, or UAT), which allows pilots to receive extended flight following and separation services due to the extended coverage of the ADS-B receiver network. Flight and traffic information is provided through UAT or SATCOM. Many corporate jets and other high-end users will have provision for passenger services such as Internet or television via satellite.

Class 2 users differ from Class 1 users in that some Class 2 users have access to AOCDL that provides operations and maintenance data via VDL-2. Additionally, in this time frame, the majority of Class 2 users will be equipped with a multimode radio that supports VDL-3 voice communications. Flight and traffic information is provided through UAT or SATCOM. Some Class 2 users may also equip for APAXS via satellite.

The Class 3 users see the greatest change in communications from the 2007 time frame. Virtually all Class 3 aircraft will be equipped with multimode radios that support controller-pilot voice and data communications via VDL-3. In addition, these aircraft will exchange performance and preference data with ATC via VDL-3 DSSDL. Flight and traffic information are provided through UAT or SATCOM. Two-way SATCOM will be available to support passenger Television and Internet services and may begin to support aircraft-AOC and aircraft-ATC data exchange.

Class 3 aircraft will be the majority users of ADS-B via the selected link (Mode-S, VDL-4, or UAT) due to the maneuvering benefits derived from equipage. HFDL will continue to be used by some aircraft to support oceanic operations.

An overview diagram of the 2015 AATT Architecture alternative using broadband satellite is shown in Figure 1.4-3 and a terrestrial broadband alternative is depicted in Figure 1.4-4.

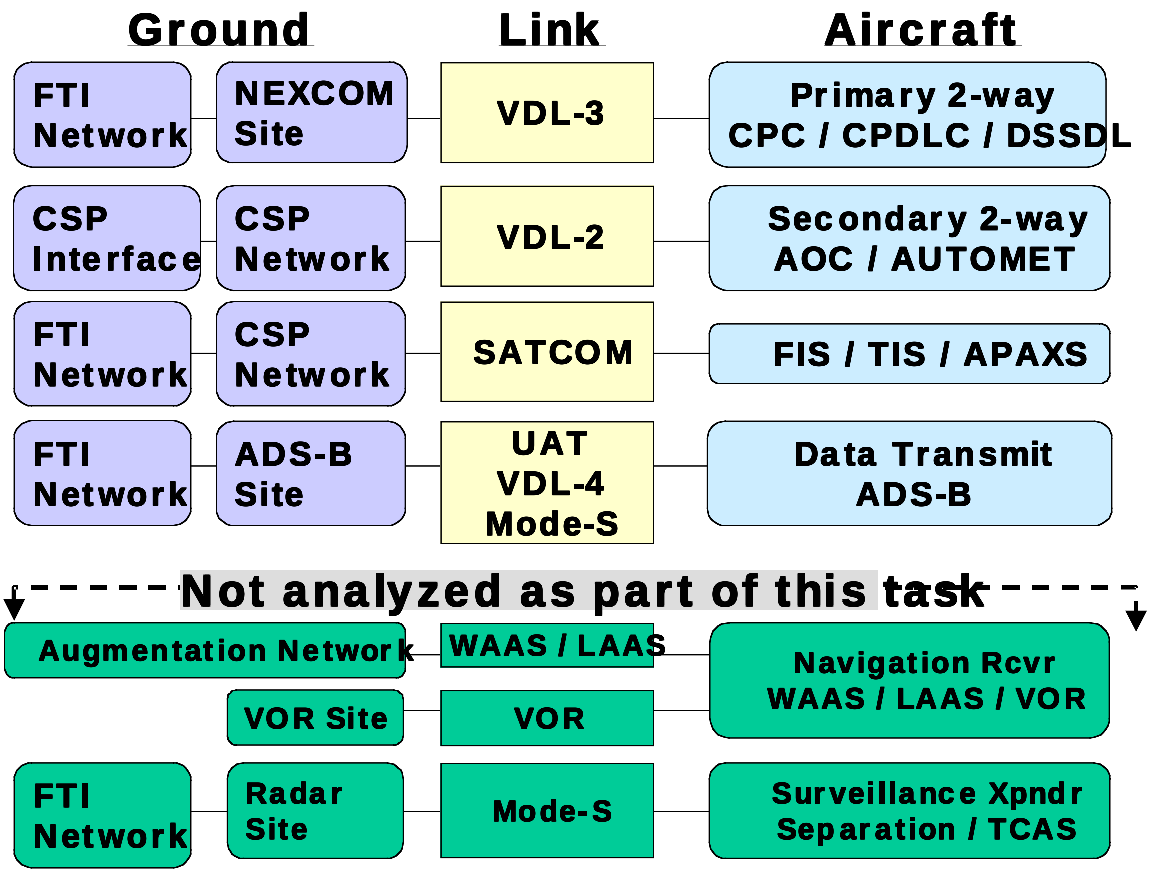

Figure 1.4-3. 2015 AATT Architecture Alternative - SATCOM Based Broadband

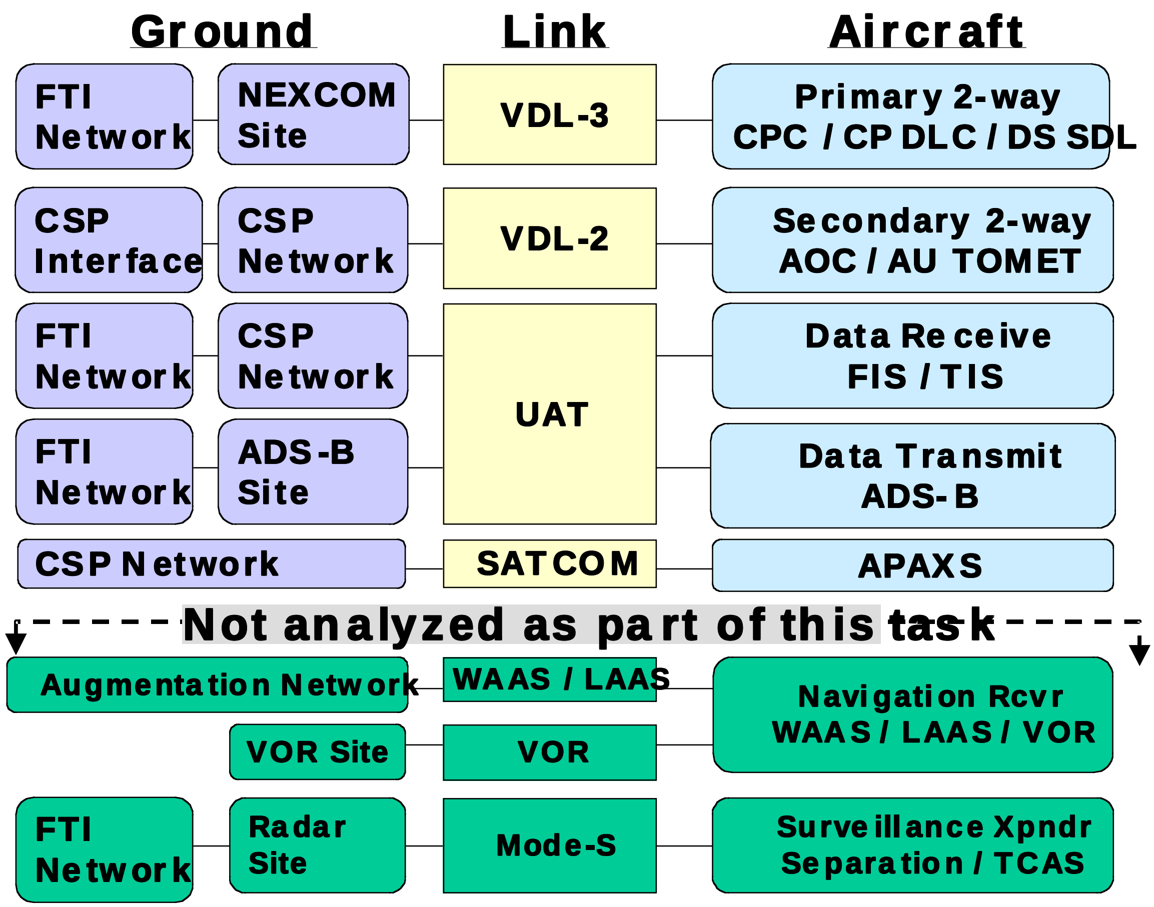

Figure 1.4-4. 2015 AATT Architecture Alternative - Terrestrial Based

2 Introduction

This report responds to a specific task under AATT Research Task Order (RTO) 24, develop AATT 2015 Communication System Architecture (CSA).

2.1 Overview of Task 5

The objective of Task 5 is to develop a 2015 AATT Communication System Architecture; i.e., to develop a communication system architecture (CSA) with the potential for implementation by 2015 that can fulfill the goal of providing the collection and dissemination of aviation related information to and from various classes of aircraft.

Task 5 is one of eleven related tasks in the AATT RTO 24, Communications System Architecture Development for Air Traffic Management and Aviation Weather Information Dissemination. The relationships among these tasks are depicted in Figure 2.1-1. Task 5 builds upon the communications system concepts developed in Task 4 and uses requirements from Task 3 to define the recommended 2015 AATT architecture. Task 6 develops the 2007 AATT Architecture, and Task 7 develops the 2007 Aviation Weather Information (AWIN) Architecture. Elements of Task 9 define and determine what is achievable in 2015. The results of these tasks all feed tasks 8, 10, and 11.

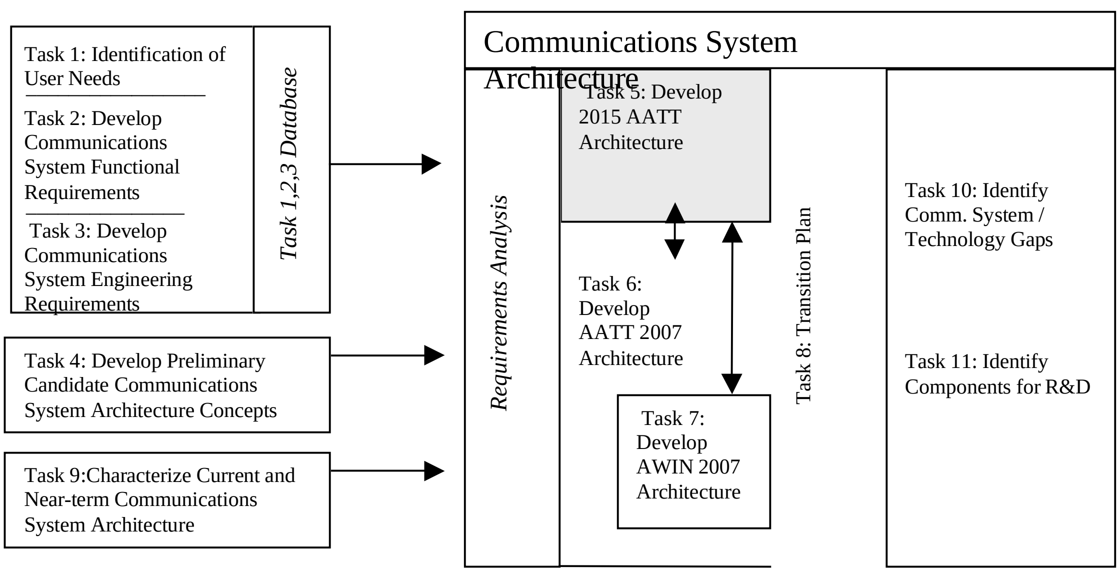

Figure 2.1-1. Relationship to Other Tasks

Task 5 began with a review of the relevant user needs and functional communications requirements collected in Tasks 1, 2, and 3 of this Research Task Order to develop a communications functional architecture for 2015 based on the nine communication technical concepts presented in Section 3 and discussed in detail in Section 3.1. The functional communication architecture was used to formulate alternative technology solutions for the physical architecture based on the results of our communication loading analysis and our determination of communication link capabilities. Concurrent with the process of defining technology alternatives for the 2015 AATT communication system architecture, we reviewed the current NAS Architecture plans to develop a "bottom up" perspective of what systems and capabilities are expected to be in place in 2015. With this "projected" definition, we were able to compare the 2015 AATT CSA technology alternatives to the bottom-up view 2015 NAS Architecture to identify the differences (or "gaps") between the two and to develop a recommended 2015 AATT Architecture. Tasks 10 and 11 will identify the gaps more comprehensively and make recommendations on areas of research or development to close them. These tasks, along with the Transition Plan task (Task 8), also will define an effective transition path from today's NAS Architecture, through a 2007 Architecture (Task 6) and the 2007 AWIN Architecture (Task 7), to the 2015 AATT CSA.

To ensure data availability to meet the needs of all users of the Air Traffic Services, three classes of users were defined as follows:

Class 1: Operators who are required to conform to FAR Part 91 only, such as low-end General Aviation (GA) operating normally up to 10,000 ft. This class includes operators of rotorcraft, gliders, and experimental craft and any other user desiring to operate in controlled airspace below 10,000 ft. The primary distinguishing factor of this class is that the aircraft are smaller and that the operators tend to make minimal avionics investments. A small number of aircraft are not equipped with radios, but these aircraft are outside the realm of a communications architecture.

Class 2: Operators who are required to conform to FAR Parts 91 and 135, such as air taxis and commuter aircraft. It is likely that high-end GA and business jets and any other users desiring to operate in controlled airspace will invest in the necessary avionics to be able to achieve the additional benefits.

Class 3: Operators who are required to conform to FAR Parts 91 and 121, such as Commercial Transports. This class includes passenger and cargo aircraft and any other user desiring to operate in controlled airspace. These users will invest in the avionics necessary to achieve the additional benefits.

Based on the user needs and functional communications requirements presented in Tasks 1 and 2, the table below presents the high level objectives to be met by the resulting communications architecture. These user goals and operational requirements have been grouped according to user class.

Table 2.1-1. User Goals and Operational Requirements

Class 1 User Goals	**Class 2 User Goals**	**Class 3 User Goals**
• Minimize/streamline interaction with ATM system • Make communications transparent and seamless for the pilot • Expand access to more airports in IMC conditions (High-end GA)	• Reduce limitations and delays caused by weather • Provide instrument approaches to more airports	• Expand the use of user preferred routes and trajectories • Increase airport capacity in IMC • Increase system predictability • Reduce weather related delays • Minimize time and path length for routing around hazardous weather
Class 1 Operational Requirements	**Class 2 Operational Requirements**	**Class 3 Operational Requirements**
Class 1 users require: • On demand weather • Weather at more sites • User friendly formats ("user friendly" includes graphical, oriented to flight path, uncluttered, easy to interpret by solo pilot, etc.) • More real-time updates	Class 2 users require: • Weather at a greater number of sites • More real-time weather at remote sites	The Class 3 users, desiring a combination of preferred routes and increased capacity, require: • More precise weather information for routing • Weather information consistent with that seen by controllers and operations centers • Higher density grids at higher update rates to support decision support systems like CTAS and wake vortex prediction systems

The information above emphasizes a flow of information that generally is ground-to-air. Aircraft will be required, however, to downlink a greater number of aircraft parameters and intent information to feed automation and decision support systems (CTAS, wake vortex prediction, etc.).

This Task 5 effort identifies the criteria and provides an assessment of the suitability of each mode of communications and communications links for each potential aviation application. These assessments concentrated on engineering requirements and addressed the benefits to specific types of users, thereby driving user equipage decisions. From a CSA perspective, the implications of airspace users that have varying levels of capability are considered, so airspace mix also is considered. Based on the supporting technical detail found throughout Section 3, the resulting recommended 2015 AATT Communications Architecture is presented in Section 3.4.

2.2 Overview of the Document

Section 1 is an executive summary that provides a high-level synopsis of this document.

Section 2 introduces the task and provides the necessary background and context, including the relationship of Task 5 to other RTO 24 tasks.

Section 3 provides a recommended 2015 Architecture in the context of the supporting technical detail used to develop the recommendation. It provides architecture concepts, characteristics, and considerations. It discusses the following topics in order:

- Our approach to developing architecture alternatives
- A summary of the 2015 AATT communication system architecture technology alternatives, including advantages and disadvantages of each in comparison to the projected 2015 NAS Architecture
- The recommended 2015 AATT communication system architecture with rationale for selection.

Section 4 presents the technical detail of the communication load analysis. It discusses the following topics in order:

- Calculation methodology
- Numerical results of the message load calculations
- Implications and conclusions drawn from the numbers.

Section 5 provides the technical details of the communications links.

- Link characteristics (SOW 4.6.1)
- Significant points and tradeoffs considered in link selection
- Network, standards, and protocol requirements for the overall architecture and for each data link, including any interoperability requirements between different networks, standards, and/or protocols
- Implications for the ground-ground communication network infrastructure in realizing/implementing the air-air and air-ground data links identified in SOW 4.6.1, along with potential mitigating solutions
- Technical obstacles with respect to gaining access and transmitting the data via the ground infrastructure.

Section 6 describes some of the characteristics of the ground-ground communications relevant to the AATT communication systems architecture.

3 Defining the 2015 Communication System Architecture

3.1 Introduction

The architecture development concepts presented in this section are not unique to Task 5 (2015 AATT Architecture); rather, they apply equally well to Task 7 (2007 AWIN Architecture) and Task 6 (2007 AATT Architecture).

The 2015 AATT Architecture provides a top-down perspective of the enabling systems that best satisfy the user requirements and operational concepts. In contrast, the 2015 NAS Architecture represents a projection of the FAA modernization path from today's NAS Architecture into the 2015 time frame. A critical and embedded aspect of the process of defining the 2015 AATT Architecture is to compare it to the 2015 NAS Architecture for the purpose of identifying gaps that can be further addressed to potentially bring the two architectures into alignment.

The analysis leading to the definition of the 2015 AATT Architecture involved the three primary tasks shown in Panel A of Figure 3.1-1: (1) defining an overall functional architecture to satisfy the desired services, (2) defining the information to be exchanged while providing the services (i.e. communication loading), and (3) identifying the enabling mechanisms (i.e. communication links) that are suitable for exchanging the information. Based on these tasks, we identified communications technology alternatives that were candidates for the 2015 AATT Architecture.

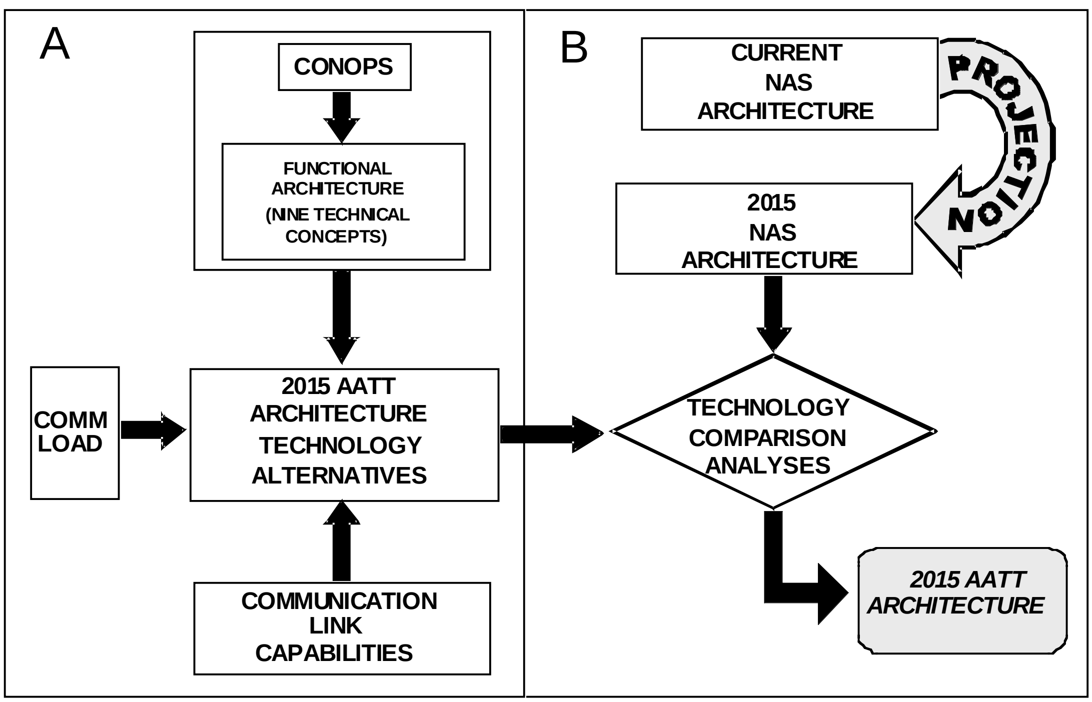

Figure 3.1-1. 2015 AATT Architecture Development Method

Definition of the functional architecture first requires an understanding of the desires of the aviation community. To gain this understanding, we reviewed a wide range of user requirements as documented in Tasks 1, 2, and 3 and drew upon knowledge gained through our team's in-depth involvement in the development of the NAS Architecture. We organized our results by air traffic services and the functional capabilities into which the services logically divide, and then matched the message type requirements that were identified in Task 2 with this service/functional capability structure. The result was a *service-driven view of the message types* that had been identified. [Note that, for our purposes, a message type is a logical grouping of information that represents all data forms within that type, including raw data, commands, images, etc.]. We then focused these message types further with crosscutting technical concepts derived from the CONOPS for the purpose of defining the functional architecture. Finally, by applying the appropriate enabling communication links to the functional architecture, we transformed it into the physical communications architecture. These relationships are illustrated in Figure 3.1-2.

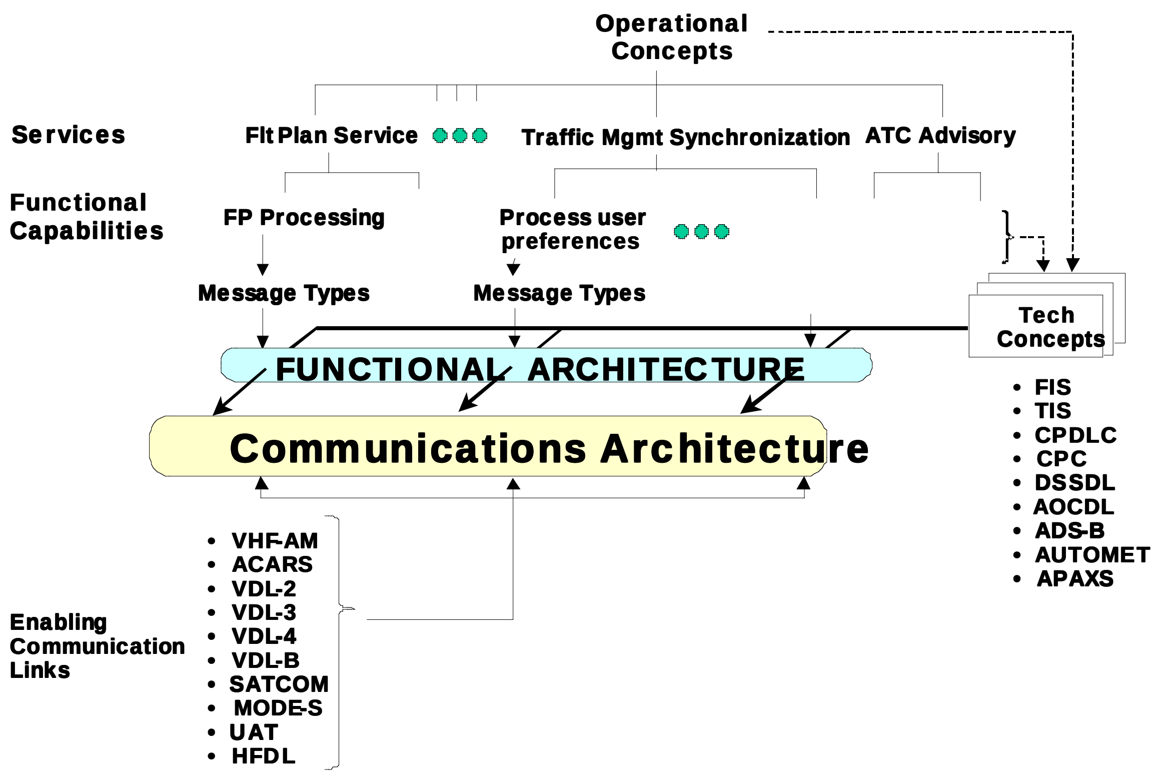

Figure 3.1-2. Operational Concepts to Communications Architecture

At the highest level are the operational concepts that provide the top down vision for what is desired. In the 2015 time frame, the drivers for the operational concepts are born out of the need for increased user flexibility with operating efficiencies and increased levels of capacity and safety to meet the growing demand for air transportation. These concepts are characterized by: (1) removal of constraints and restrictions to flight operations, (2) better exchange of information and collaborative decision making among users and service providers, (3) more efficient management of airspace and airport resources, and (4) tools and models to aid air traffic service providers.

The operational concepts provide a context for measuring progress and for assessing whether or not the infrastructure is being provided to support the vision. The vision provided by the operational concepts draws upon the results of efforts such as the ATS Concept of Operations for the National Airspace System in 2005, the Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM), and current and emerging industry trends.

From a communication architecture perspective, it is important to understand the services that will enable the operational concepts, along with their supporting functions and the various message types that are the products of those functions. The services identified for this task and their related functional capabilities were identified in Tasks 1,2, and 3 and are summarized in Table 3.1-1, which also includes the Message Type Identifiers for the information exchange to support these functional capabilities.

Table 3.1-1. Services and Associated Functional Capabilities

Service	Function Name (Functional Capability)	Msg ID (M#)
Aeronautical Operational Control (AOC)	Collaborate with ATM on NAS Projections and User Preferences	M25
	Monitor Flight Progress - AOC	M23
		M33
		M6
	Airline Maintenance Support	M8-M12
	Schedule; Dispatch; and Manage Aircraft Flights	M30
ATC Advisory Service	Provide In-flight NAS Status Advisories	M17
	Provide In-flight or Pre-flight Traffic Advisories	M32
	Provide In-flight or Pre-flight Weather Advisories	M13
		M14
		M15
		M18
		M20
		M21
		M22
		M26
		M27
		M28
		M29
		M35
		M37
		M39
		M4
Flight Plan Services	File Flight Plans and Amendments	M22
		M24
		M32
	Process Flight Plans and Amendments	M16
		M32
		M34
		M40
On-Board Service	Provide Administrative Flight Information	M5
		M7
	Provide Public Communications	M31, 41, 42
Traffic Management Strategic Flow Service	Provide Future NAS Traffic Projections	M38
Traffic Management Synchronization Service	Process User Preferences	M2
	Project Aircraft In-flight Position and Identify Potential Conflicts	M1
		M3
	Provide In-flight Sequencing; Spacing; and Routing Restrictions	M36
	Provide Pre-flight Runway; Taxi Sequence; and Movement Restrictions	M32
		M36

Table 3.1-2 below provides a textual description of the Message Type corresponding to each Message Type Identifier. These messages may be voice, text, or graphical images.

Table 3.1-2. Message Types and Message Type Identifiers

Message Type Identifier	Message Type
M1	ADS
M2	Advanced ATM
M3	Air Traffic Information
M4	Not used - see M43, M44
M5	Airline Business Support: Electronic Database Updating
M6	Airline Business Support: Passenger Profiling
M7	Airline Business Support: Passenger Re-Accommodation
M8	Airline Maintenance Support: Electronic Database Updating
M9	Airline Maintenance Support: In-Flight Emergency Support
M10	Airline Maintenance Support: Non-Routine Maintenance/ Information Reporting
M11	Airline Maintenance Support: On-Board Trouble Shooting (non-routine)
M12	Airline Maintenance Support: Routing Maintenance/ Information Reporting
M13	Arrival ATIS
M14	Not used - see M43, M44
M15	Convection
M16	Delivery of Route Deviation Warnings
M17	Departure ATIS
M18	Destination Field Conditions
M19	Diagnostic Data
M20	En Route Backup Strategic General Imagery
M21	FIS Planning – ATIS
M22	FIS Planning Services
M23	Flight Data Recorder Downlinks
M24	Flight Plans
M25	Gate Assignment
M26	General Hazard
M27	Icing
M28	Icing/ Flight Conditions
M29	Low Level Wind Shear
M30	Out/ Off/ On/ In
M31	Passenger Services: On Board Phone
M32	Pilot/ Controller Communications
M33	Position Reports
M34	Pre-Departure Clearance
M35	Radar Mosaic
M36	Support Precision Landing
M37	Surface Conditions
M38	TFM Information
M39	Turbulence
M40	Winds/ Temperature
M41	System Management and Control
M42	Miscellaneous Cabin Services

Message Type Identifier	Message Type
M43	Aircraft Originated Ascent Series Meteorological Observations
M44	Aircraft Originated Descent Series Meteorological Observations

Given a definition of the message types that require air-ground communication, the next step was to organize them further in a logical fashion that supports the development of a functional communication architecture. To accomplish this organizational construct, we examined the operational concepts and the service functional capabilities to identify ways to focus the functional architecture. Based on that examination, we defined nine unique technical concepts related to air ground communications that span the functional capabilities and that can be used to drive the definition of the functional architecture. These technical concepts are defined in Table 3.1-3 below:

Table 3.1-3. Air-Ground Communications Technical Concepts

Technical Concept Definition	Technical Concept Name
Aircraft continually receive Flight Information to enable common situational awareness of weather and NAS status	Flight Information Services (FIS)
Aircraft continually receive Traffic Information to enable common situational awareness of the traffic in the area	Traffic Information Services (TIS)
Controller-Pilot data messaging supports efficient Clearances, Flight Plan Modifications, and Advisories	Controller-Pilot Data Link Communications (CPDLC)
Controller-Pilot voice communication to support ATC operations	Controller-Pilot Communications (CPC)
Aircraft exchange performance / preference data with ATC to optimize decision support	Decision Support System Data Link (DSSDL)
Pilot-AOC data messaging supports efficient air carrier/air transport operations and maintenance	Airline Operational Control Data Link (AOCDL)
Aircraft broadcast data on their position and intent continuously to enable optimum maneuvering	Automated Dependent Surveillance-Broadcast (ADS-B)
Aircraft report airborne weather data to improve weather nowcasting/forecasting	Automated Meteorological Reporting (AUTOMET)
Commercial service providers supply in-flight television, radio, telephone, entertainment, and internet service	Aeronautical Passenger Services (APAXS)

Using these technical concepts as drivers, we next defined the functional architecture for air ground communications as shown in Figure 3.1-3.

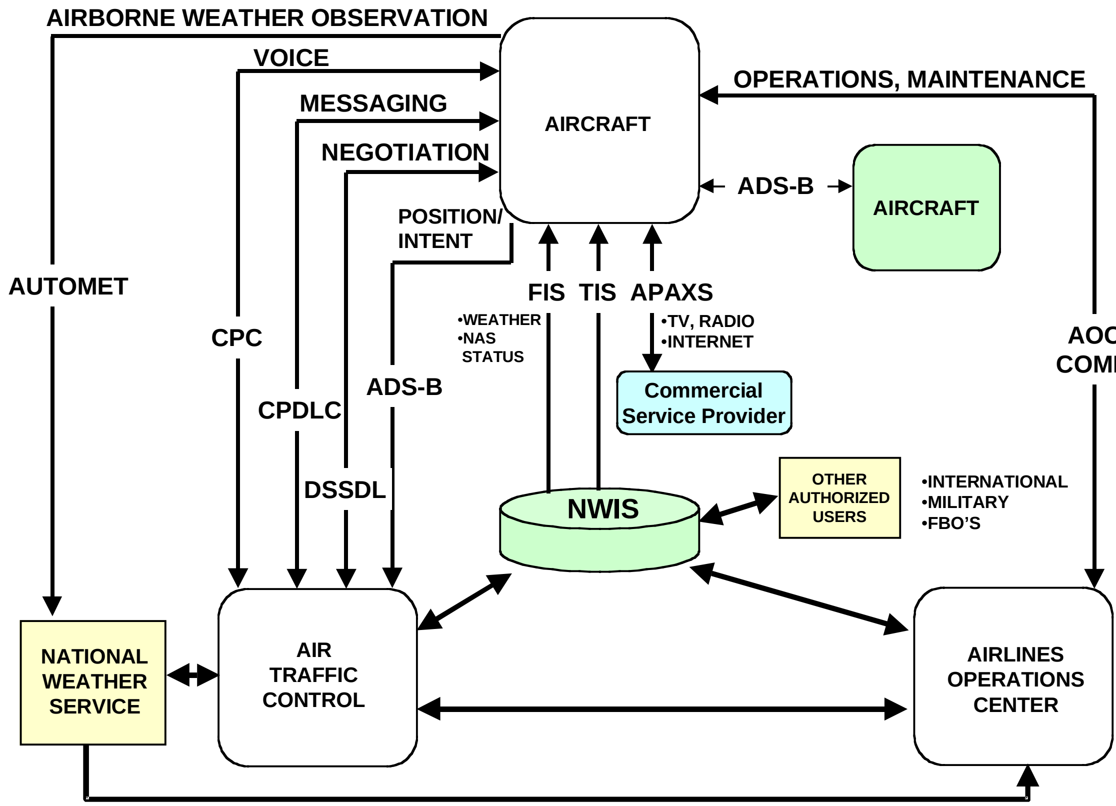

Figure 3.1-3. Functional Architecture for Air-Ground Communications

Our next step was to organize the functional capability message types into categories that are associated with each technical concept. The following table shows the resulting message categories, including message content for each category, mapped to the individual technical concepts listed in Table 3.1-4.

Table 3.1-4. Message Categories Mapped to Technical Concepts

Category.	Technical Concept	Description of Concept
1	Flight Information Services (FIS)	Aircraft continually receive Flight Information to enable common situational awareness
2	Traffic Information Services (TIS)	Aircraft continuously receive Traffic Information to enable common situational awareness
3	Controller-Pilot Data Link Communications (CPDLC)	Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories (including Hazardous Weather Alerts)
4	Controller Pilot Communications (CPC) Voice	Controller - Pilot voice communication
5	Decision Support System Data Link (DSSDL)	Aircraft exchange performance / preference data with ATC to optimize decision support
6	Airline Operational Control Data Link (AOCDL)	Pilot - AOC messaging supports efficient air carrier/air transport operations and maintenance
7	Automated Dependent Surveillance (ADS) Reporting	Aircraft continuously transmit data on their position and intent to enable optimum maneuvering

Category.	Technical Concept	Description of Concept
8	Automated Meteorological Reporting (AUTOMET)	Aircraft report airborne weather data to improve weather nowcasting and forecasting
9	Aeronautical Passenger Services (APAXS)	Commercial service providers supply in-flight television, radio, telephone, entertainment, and internet service

The organization of message types into the categories listed above is listed in Table 3.1-5.

Table 3.1-5. Organization of Message Types into Message Categories

Message Category	Message Category Identifier	Message Type Identifier	Message Type
FIS	1	M13	Arrival ATIS
	1	M15	Convection
	1	M17	Departure ATIS
	1	M18	Destination Field Conditions
	1	M20	En Route Backup Strategic General Imagery
	1	M21	FIS Planning – ATIS
	1	M22	FIS Planning Services
	1	M26	General Hazard
	1	M27	Icing
	1	M28	Icing/ Flight Conditions
	1	M29	Low Level Wind Shear
	1	M35	Radar Mosaic
	1	M37	Surface Conditions
	1	M38	TFM Information
	1	M39	Turbulence
	1	M40	Winds/ Temperature
TIS	2	M3	Air Traffic Information
CPDLC	3	M24	Flight Plans
	3	M29	Low Level Wind Shear
	3	M32	Pilot/ Controller Communications
	3	M33	Position Reports
	3	M34	Pre-Departure Clearance
	3	M41	System Management and Control
DSSDL	5	M2	Advanced ATM
	5	M16	Delivery of Route Deviation Warnings
	5	M24	Flight Plans
AOCDL	6	M9	Airline Maintenance Support: In-Flight Emergency Support
	6	M10	Airline Maintenance Support: Non-Routine Maintenance/ Information Reporting
	6	M11	Airline Maintenance Support: On-Board Trouble Shooting (non-routine)
	6	M12	Airline Maintenance Support: Routing Maintenance/ Information Reporting
	6	M19	Diagnostic Data
	6	M23	Flight Data Recorder Downlinks
	6	M25	Gate Assignment
	6	M30	Out/ Off/ On/ In
	6	M8	Airline Maintenance Support: Electronic Database Updating

Message Category	Message Category Identifier	Message Type Identifier	Message Type
ADS-B	7	M1	ADS
AUTOMET	8	M43	Aircraft Originated Ascent Series Meteorological Observations
	8	M44	Aircraft Originated Descent Series Meteorological Observations
APAX	9	M5	Airline Business Support: Electronic Database Updating
	9	M6	Airline Business Support: Passenger Profiling
	9	M7	Airline Business Support: Passenger Re-Accommodation
	9	M31	Passenger Services: On Board Phone
	9	M42	Miscellaneous Cabin Services

At this point, having established a functional architecture and a corresponding relationship to the message types, we can combine it with the results of the communication load analysis (Section 4.0) and the communication link analysis (Section 5.0) to develop suitable technology alternatives for the 2015 AATT physical communication system architecture. This development of technology alternatives begins with Section 3.2 where the applicable communication links are identified for each technology concept, and a comparison is made with the NAS Architecture, projected to 2015, for purposes of gap comparison and as part of developing a recommended 2015 AATT CSA.

3.2 2015 AATT Communication System Architecture Development

The 2015 time frame represents the final phases of transition from the era of analog voice communication and islands of diverse information to an era of digital data exchange through integrated networks using shared data. The results of this transition are a collection of systems and procedures that efficiently use the capacity of the NAS while balancing access to all user classes and maintaining the highest levels of safety. As depicted in Figure 3.2-1, efficient collaboration among users is built on a foundation of shared data. This data can be divided logically into a static component representing data that changes infrequently (such as maps, charts, etc.) and a dynamic component representing data that changes frequently (such as the weather, traffic flow status, and aircraft position). This information base provides common situational awareness to all users who choose to participate. The challenge in maintaining the information base is to keep the dynamic data current for all participating users so that optimum decisions can be made. Given a common information base, decision support systems can analyze this data continuously to develop optimum solutions for individual aircraft trajectories as well as trajectories for groups of aircraft. This negotiation takes place between aircraft DSS tools and between aircraft and ATC DSS tools. When optimum solutions (or inability to find a solution) are determined, pilots and controllers are notified for confirmation (or other appropriate action). This action takes the form of strategic collaborative decision making or tactical control. In either event, data exchange continues using specified data link messages with voice communication used when it is the only practical means.

In 2015, there still will be a range of users who will choose to participate at various levels of equipage from voice only through multi-mode radios and fully modular avionics. All users are accommodated, however, and will receive benefits commensurate with their levels of equipage.

The remainder of this section develops the 2015 AATT communications system architecture based on the set of technical concepts presented in Figure 3.1-3 and briefly outlined above. Each subsection begins with a description of the technical concept and the introduction of a concept single line drawing. The purpose of the single line drawing is to highlight the end-to-end connectivity required at the concept level necessary to execute the technical concept. This provides a structure that allows us to determine technical as well as concept gaps. Next, the communication load requirements for the concept are discussed followed by an identification of the communication link alternatives that could satisfy the load requirements. Finally, the NAS Architecture approach for the concept is identified. The NAS Architecture is the FAA's fifteen-year strategic plan for modernization of the NAS. The objective of NAS modernization is to add new capabilities that will improve efficiency, safety and security while sustaining existing services.

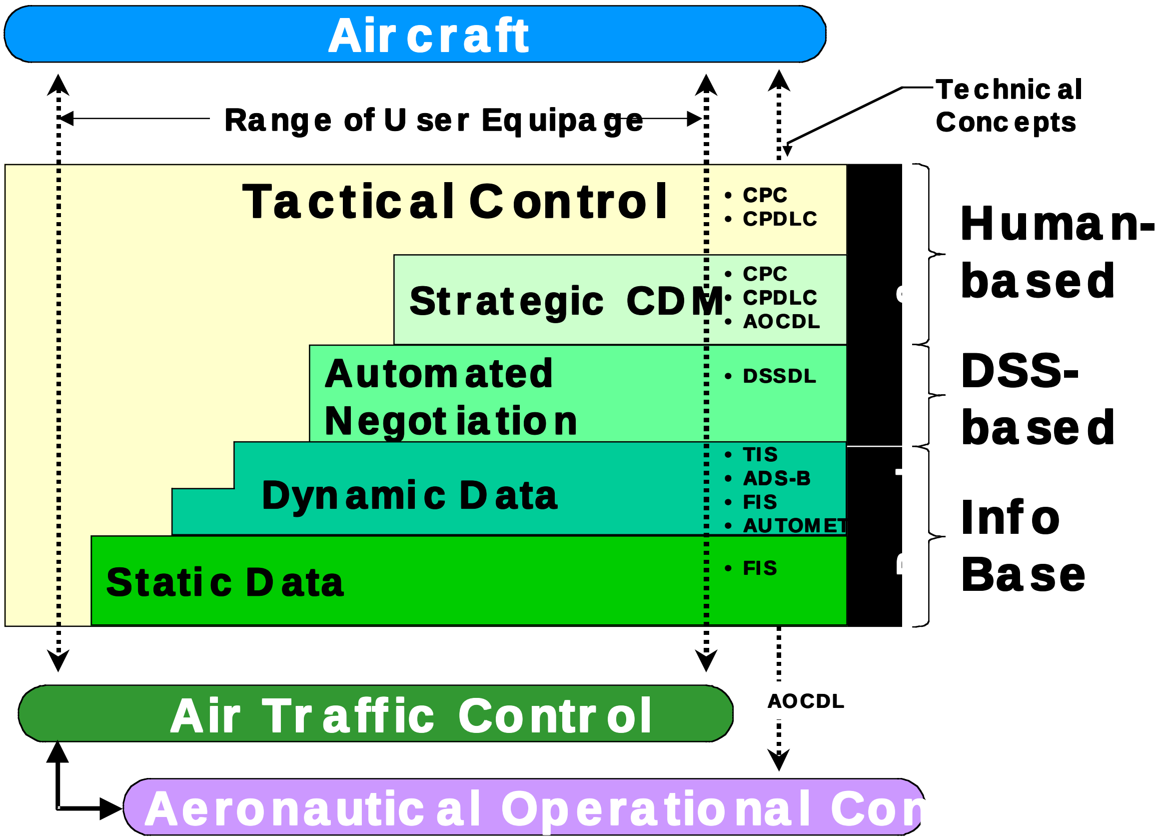

Figure 3.2-1. Air-Ground Communications Levels

3.2.1 Flight Information Services (FIS)

The FIS technical concept provides one of the foundation functions for maintaining the static and dynamic data requirements for the information base of the NAS. In this concept, aircraft receive flight information continuously in order to enable common situational awareness for pilots that supports their ability to operate safely and efficiently within the NAS. Flight information consists of NAS weather information, NAS status information and NAS traffic flow information. Flight information is considered advisory and for the purposes of air-ground communications is classified as routine (see section 4.2 for further details). FIS information is intended for transmission to all classes of users. Thus, any selected link alternative must be capable of installation and use in any aircraft regardless of class. The single line diagram for FIS is shown in Figure 3.2-2.

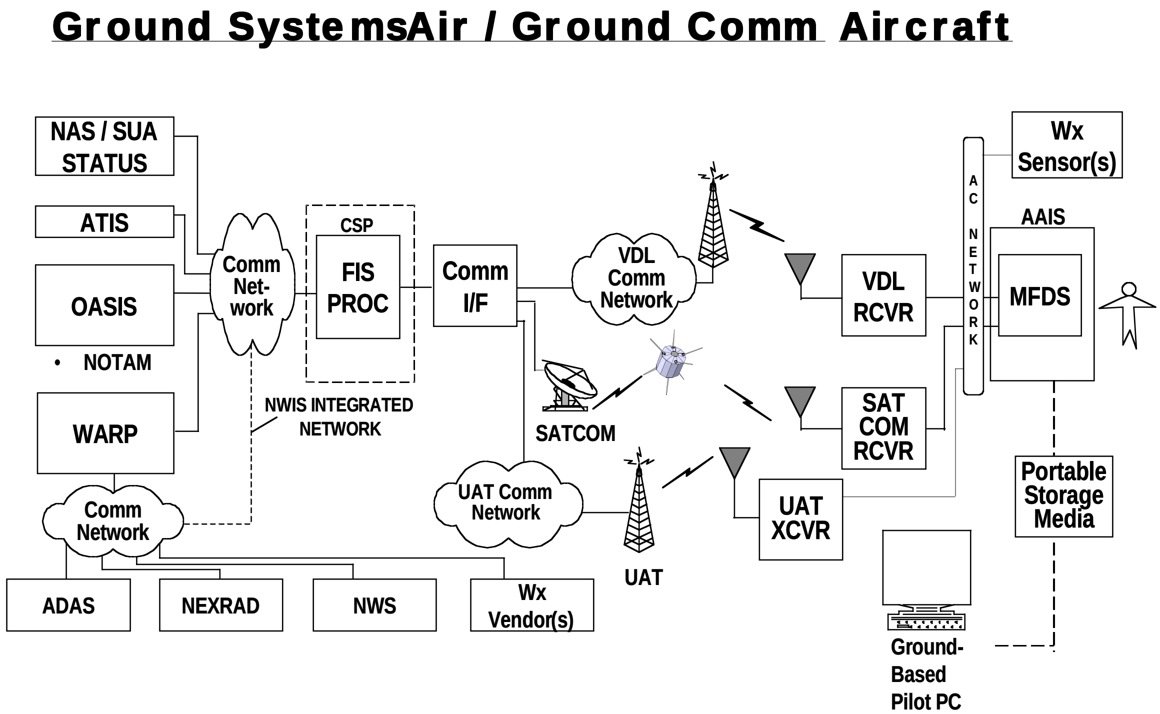

Figure 3.2-2. Flight Information Service in 2015

The Weather products transmitted via FIS may include observations and forecasts, weather radar data, winds and temperature aloft, and gridded forecast data. The NAS status information may include NOTAMs, airport conditions and configurations, and active/inactive status of special use airspace. NAS traffic flow information may include active and pending restriction data, and other traffic flow initiative information.

During the requirements analysis conducted in Tasks 1 through 3, it was thought that some types of FIS products might be tailored for a specific flight and delivered only to an aircraft that requested it, while other FIS products were not flight specific and would be suitable for broadcasts. In this form the messages require conversion from 2-way to broadcast or vice versa for our analysis. These message types are shown in Table 4.3-5 and Table 4.3-6.

For FIS, the NAS Architecture plans to rely on commercial service providers to supply products regionally to the aircraft via four allocated 25kHz VHF frequencies using VDL-B.

Our communication load estimate for broadcast FIS is the same for 2007 as for 2015 as we were unable to identify any additional products. If there were no growth in load, the architecture could be sustained with technology refresh as systems become obsolete. The FIS load data is derived from Table 4.5-6 and Table 4.5-7.

For the initial analysis, the architecture was evaluated with FIS data transmitted to the aircraft using a two-way (request/reply) data link or a transmit-only broadcast data link, depending on the message type, as identified in Tasks 2 and 3.

In order to get a domain broadcast estimate we combine the FIS flight specific and non-flight specific data (Table 4.3-10) and make the appropriate unit conversions to produce Table 3.2-1. For purposes of estimation, if we assume a region consisting of one en route center, a consolidated terminal area and four airports, then the total communication requirement for the region would be 7.2 kbps on the broadcast link and 66 kbps on the two-way link. This greatly exceeds the capacity of a VDL channel, precluding the use of this approach on the channels currently allocated for FIS. In addition, this approach would require the use of separate radios for broadcast and two-way FIS and complicated avionics to combine the results on a display.

Table 3.2-1 FIS 2-way + broadcast Communication Load Requirements (kilobits per second)

	Airport	Terminal	En Route	Total
FIS – Domain	9.9	9.4	17.2	
Region (x) [1]	39.6 (4)	9.4 (1)	17.2 (1)	66
FIS - Regional Broadcast		0.6	6.6	7.2

Note: (x) is domain multiplier

Even for information of a general nature, it could be delivered to every flight over two-way links. Given the dynamic nature of FIS data, however, a two-way data link would require a constant request/reply method that is inefficient in terms of channel overhead and suffers in performance directly proportional to the number of aircraft (see Section 4.3.2). Our estimate of the two-way communication loading for FIS (if all messages were two-way) identifies the need for uplinks ranging 1373 kbps for 2015 in a geographic area covering airspace for four airports, a consolidated TRACON, and en route. This far exceeds any VDL link capacities and would require a move to Broadband links. Detailed analysis included applying overhead factors for two-way communications to all non-flight specific messages; since this is not considered a viable solution, the details analysis is not included here.

From a communication standpoint, broadcast communication is considered desirable for FIS because it is the most efficient in terms of overhead and component design. There are two methods that we considered for aggregating broadcast data: single channel and multi-channel.

Aggregate – Single Channel:

In this method, all data for transmission is collected and transmitted on a single channel. This requires that all data must be received and processed onboard the aircraft in order to select the specific FIS data of interest.

The advantage for this method is that there is a single channel that can be monitored to receive all data. This is the least complex implementation method. The disadvantage can come when the total data set becomes so large that is takes an unacceptable amount of time to transmit it to the aircraft. For FIS we feel that 5 minutes is a good upper bound for total data transmission. This would mean that whatever FIS data the aircraft operator used would have a transmission latency of no more than 5 minutes.

Aggregate – Multi-Channel:

In this method, all data for transmission is collected and divided into logical data sets that are each transmitted on their own channel. This method is similar to “Cable TV” where each channel carries a unique set of data. In this method a processor onboard the aircraft would only listen to the channels that contained data of interest. The advantage for this method is faster data updates. The disadvantage is the added complexity of the processing algorithms and the need for additional channels. Once again, we feel the goal should be the receipt of any desired data within 5 minutes.

Either of these methods can be applied to a local, regional, or national level. The most desirable for FIS would be a national aggregate single channel broadcast because of its simplicity of implementation.

If the messages identified in Table 4.4-3 as two-way messages for FIS were instead broadcast, at the same frequencies as shown in the table, the total communication load would be reduced to the loads shown in Table 3.2-2. Note that the communication load is reduced not only because products are transmitted only once for all aircraft to receive, but also because the protocol overhead for broadcast is less than the overhead for two-way communication.

Table 3.2-2 FIS Communication Load Requirements (kilobits per second) to Broadcast all FIS Message Types

	Airport	Terminal	En Route	Total
FIS - Domain	0.2	0.9	6.9	
FIS - Region	1.0 (5)	4.5 (5)	6.9 (1)	12.4
FIS - National				248 (20)

Note: (x) is domain multiplier

Using the same example of a region including en route airspace and five airports and terminals, the total load requirement is 12.4 kbps. This is within the capacity of a VDL-B channel. One disadvantage of regional coverage is that the pilot can only receive FIS data for the region that they are flying in. In some situations this can limit the pilots ability to perform strategic planning.

Aggregation of this data to a national level can conservatively be estimated by multiplying the regional estimate by 20 (the number of CONUS centers). This yields a national broadcast load of 248 kbps. This would exceed the capacity of any VDL link but could be supported by UAT or SATCOM links.

Technology Gap

One of the greatest challenges to national implementation of FIS (including region by region) is establishment of the A/G ground network. From this aspect, the establishment of a multi-use broadband data exchange network becomes more appealing. Our analysis indicates that VDL-B can accommodate the delivery of FIS data to the aircraft if performed on a regional basis and given the assumptions for data size and compression ratios identified in Section 4.3. National broadcast or two-way FIS implementations will require the higher capacity solutions that are currently in the early stages of implementation. A summary of the possible FIS communication links is shown in Table 3.2-3.

The government should explore innovative methods for establishing a national air-ground broadband data exchange network. This effort should cover all aspects of the air-ground network from location to physical access to operation and maintenance. For example, the government could make their terrestrial air-ground communication sites accessible to commercial service providers, even potentially turning them over to third parties for operation and maintenance, as many wireless telecommunication providers are doing today.

Table 3.2-3 FIS Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Aircraft continuously receive Flight Information to enable common situational awareness	FIS					✓		✓	✓	
✓ Acceptable Alternative		NAS Architecture		AATT CSA Recommendation						

3.2.2 Traffic Information Services (TIS)

The TIS technical concept is another of the foundation functions necessary for maintaining the dynamic data requirements for the information base of the NAS. In this concept, aircraft receive trajectory information of all aircraft continuously in order to enable common situational awareness for pilots that enhances their ability to operate safely and efficiently within the NAS. TIS information consists of real time aircraft position data that is received by ATC from their ground-based surveillance sensor network consisting of primary and secondary radars and dependent surveillance receivers. The received aircraft position data is combined with trajectory and intent data and then broadcast to participating aircraft. TIS information is provided without any ground controller involvement. TIS information is used onboard the aircraft to support tactical maneuvering and trajectory planning decisions by the pilot. The performance requirements for transmission of TIS data to support tactical maneuvering are much more stringent (0.5 seconds) than for support of trajectory planning (120 seconds). To be useful for trajectory planning for ten or twenty minutes ahead, the TIS information needs to cover a large volume of airspace. The recommended architecture supports tactical maneuvering and trajectory planning, so the communication loading is much higher than if only tactical maneuvering were supported. The end-to-end connectivity diagram for TIS is shown in Figure 3.2-3.

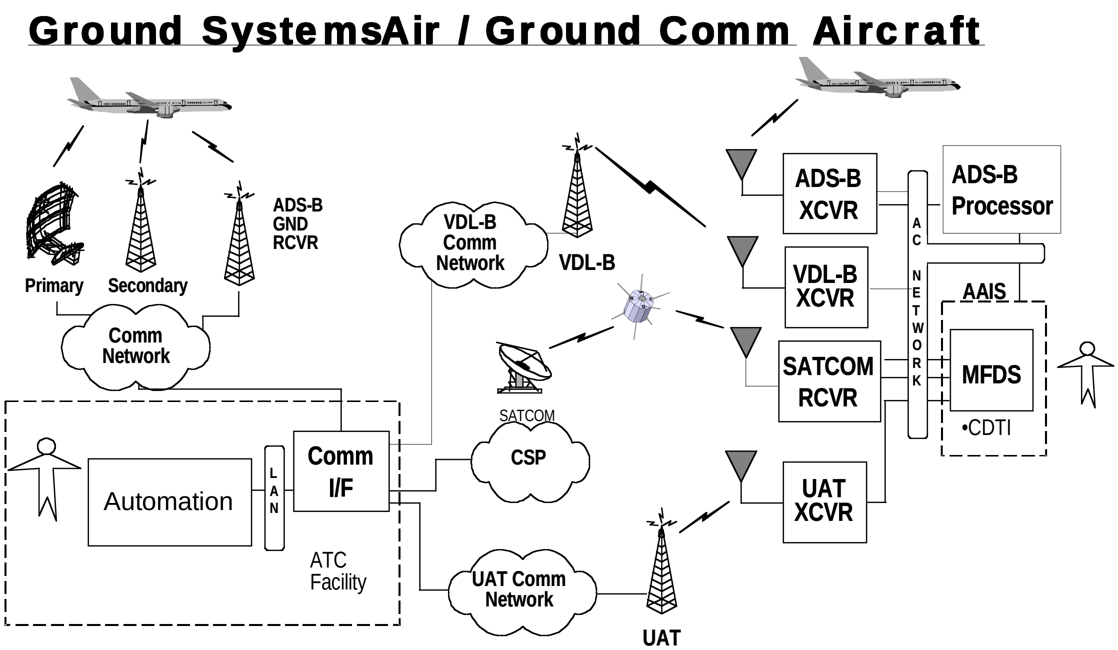

Figure 3.2-3 TIS Connectivity Diagram in 2015

TIS has been identified for broadcast communication. Broadcast communication is considered desirable because it is the most efficient in terms of overhead and design. There are two methods that we considered for implementation of broadcast data.

Aggregate – Single Channel:

All data for transmission is collected and transmitted on a single channel. In this method all data must be processed onboard the aircraft in order to select the data of interest.

The advantage for this method is that there is a single channel that can be monitored by all aircraft to receive all data. This is the least complex implementation method. The disadvantage can come when the total data set becomes so large that it takes an unacceptable amount of time to transmit. In the case of TIS there are two different data sets as described above. For the "maneuvering" data set we feel that data transmission every 0.5 seconds is required in order to meet the performance requirements for decision support in maneuvering the aircraft. This would mean that whatever data you used would have a transmission latency of no more than 0.5 seconds[1]. For the "trajectory planning" data set we feel that data transmission every 2 minutes is adequate to support long range trajectory planning.

Aggregate – Multi-Channel:

All data for transmission is collected and divided into logical data sets that are each transmitted on their own channel. This is similar to "Cable TV" where each channel carries a unique set of data. In this method a processor onboard the aircraft would only listen to the channels that contained data of interest. The advantage for this method is faster updates. The disadvantage is more complex processing algorithms and the need for additional channels. Once again, for TIS, we feel the goal should be the receipt of maneuvering data within 0.5 seconds and trajectory planning data within 2 minutes.

These methods can be applied to local, regional, or national levels. The most desirable communication method for TIS would be a national aggregate single channel broadcast because of its simplicity of implementation. Our communication load analysis for national TIS (see Table 4.5-8) indicates that 425 kbps is required. This exceeds the capacity of any VDL link and would require the implementation of a UAT or SATCOM solution. Breaking the load into regional or local implementations (see Table 4.5-7) brings the requirement within the capacity of VDL-B.

Implementing a VDL-B solution, however, is problematical in that each VDL channel would require an additional 25kHz VHF frequency in each sector or region of implementation to avoid inerference. This could not be supported under the current frequency allocation scheme meaning that implementation of a multi-channel VDL-B solution would need to wait until frequencies have been reallocated as a part of the NEXCOM implementation. This will begin in 2010 and will be complete by 2015. One implication of waiting until the 2010-2015 time frame, however, would be the restriction of early maneuvering benefits for ADS-B since without TIS (or 100% ADS-B equipage) the pilot has no assurance of complete traffic situational awareness while conducting a maneuver. An additional, and potentially even more problematic implication, is that these frequencies are the same ones that would be required for the DSSDL concept, which would be using VDL-3. Given these considerations it is not recommended that TIS be implemented within the 118MHz – 137MHz aviation spectrum.

The volume of traffic information depends on the number of aircraft, since data must be included in the TIS broadcast for each aircraft in the airspace. Table 3.2-4 shows the peak data rate volumes. For a volume of airspace including five airports, five terminal and en route, the peak volume would be 50.5 kbps.

Table 3.2-4 TIS Communication Load Requirements (kilobits per second)

	Airport	Terminal	En Route	Total
TIS - Domain	21.3	6.4	18.5	
TIS - Region	N/A	32.0 (5) [1]	18.5	50.5
TIS - National	N/A	52.7 [1139] [2]	153.2 [4140]	205.9

Note 1: Region defined as 1 En Route, 5 Terminal
Note 2: National Peak Total number of aircraft per domain

[1] We specify transmission latency versus data latency to differentiate between how often the data is transmitted versus how often the data is refreshed.

In our analysis there are only 2 other links to consider that offer enough performance to support TIS: UAT and SATCOM. UAT offers link performance in the range of 1 Mbps that would easily support the TIS requirement. SATCOM offers link performance in the range of 2 Mbps that would also easily support the TIS requirement. Table 3.2-5 provides an overview of UAT and SATCOM. One potential advantage of using UAT would be that the majority of aircraft would already have a UAT radio (if it is the technology chosen for ADS-B) and a UAT terrestrial network would have been established. An advantage of SATCOM would be the wide area access provided without the need for a terrestrial network and the ability to use a commercial service provider. Each of these links is currently in the developmental stages and requires further research to establish their viability.

Table 3.2-6 provides a summary of the TIS communication links. The NAS Architecture currently identifies Mode-S as the recommended communications link for TIS. Based on our load analysis, however, we do not feel that Mode-S will be capable of supporting TIS in 2015.

Table 3.2-5 UAT and SATCOM overview

	UAT	Ka SATCOM
Base	• Terrestrial • FAA Radar, Navigation and/or Air-Ground Communication sites	• Space • Assume desirable CONUS coverage • Commercial service providers
Capacity	1Mbps	≥ 2Mbps
PRO's	• If selected as ADS-B link, all aircraft would eventually have UAT radio • Use of FAA sites • Avionics design complete – standards in development	• CONUS coverage without maintenance of terrestrial network • Higher data rates • Most likely will be available from commercial service providers
CON's	• Maintenance of terrestrial network • Additional radio required if not selected as part of ADS-B • Most likely will require FAA ownership and operation – currently no funding identified	• Immature avionics design - no standards – unproven for small GA aircraft • Additional radio required

Table 3.2-6 TIS Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Aircraft continuously receive Traffic Information to enable common situational awareness	TIS							✓	✓	
✓ Acceptable Alternative		☐ NAS Architecture				★ Restricted Operation				

Technology GAPS

The gaps associated with the implementation of TIS via UAT or SATCOM are the identification of suitable spectrum (independent of that used for ADS-B, in the case of UAT) and the development of antennas and avionics that are suitable for use on all aircraft.

Initial UAT avionics design is complete with field testing due to begin in the fall of 2000 as part of the Safe Flight 21 CAPSTONE program. Use of satellite communication links requires the demonstration of aeronautical mobile technologies for antenna, receivers, link algorithms, protocols, and standards. A major technology focus for broadband communications services is the need to provide more bandwidth (with a focus on Ka-band). Given the migration to these frequencies, the need exists for higher efficiency transmitters (both space and terrestrial), more adaptive bandwidth versus power efficient modulation, forward error correction coding (including turbo codes and bit/modulation symbol interleaving), and much expanded use of variable bit rate formats and dynamic multiplexing techniques such as asynchronous transfer mode (ATM) based technologies. Antennas and receivers must be adapted for the aviation market (size, weight, cost) and must overcome the problems of rain attenuation for broadcast TIS over satellite.

3.2.3 Controller-Pilot Communications (CPC)

Voice communication is the foundation of air traffic control. Thus, even as we move toward a higher utilization of data exchange for routine communications, it is critical to maintain a high quality, robust voice communication service. The implementation of NEXCOM will provide both digital voice and data capabilities. New multi-mode radios will be able to emulate the existing VHF-AM analog modulation and other selected modulation techniques using software programming.

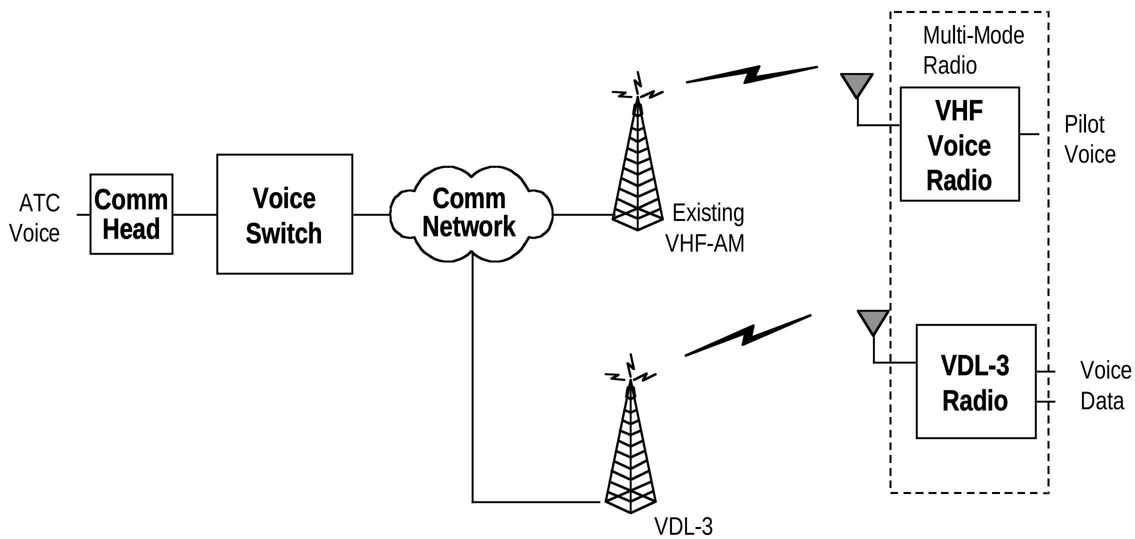

Figure 3.2-4. CPC Air/Ground Voice Communication in 2015

The CPC communication links are shown in Table 3.2-8. The NAS Architecture plans to transition controller pilot voice communication to an FAA supported VDL-3 network in the 2010-2015 time frame. Our VDL-3 link analysis indicates that a single VDL-3 sub-channel supports 4.8 kbps. Our communication load analysis indicates that a single VDL-3 sub-channel is sufficient to support controller pilot communication under worst case loading conditions. We therefor recommend that the AATT CSA maintain the NAS Architecture recommendation.

Table 3.2-7 CPC Load Analysis Results

Class	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
1	2.7	1.3	0.7	0.7	2.0	0.5
2	0.9	0.4	0.3	0.3	0.2	0.1
3	1.2	0.5	0.0	0.0	0.0	0.0
Total	7.0		1.9		2.7	
Voice Channels Required (P=0.2)	8		3		4	

Table 3.2-8 CPC Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Controller - Pilot voice communication	CPC	✓		✓						
✓ Acceptable Alternative		☐ NAS Architecture			★ Restricted Operation					

Technology Gap

CPC provides the voice communications capability for the NAS. Provisions of CPC via packetized data communication will transition in 2010-2015. From a technology gap standpoint, there are concerns in the area of voice digitization. Further research can be performed to improve the digital voice compression techniques at rates of 4800 bps. Additionally, our estimate for peak traffic loading (described in Section 4.5.4) indicates that the maximum number of voice channels required to support the En Route domain is 6. Under the current scheme for implementation of voice channels, however, there is one channel dedicated to each sector. A typical en route center can have approximately 40 sectors – or 40 channels. Thus, the development of a virtual network that could eliminate the need for dedicated channels (while maintaining adequate margins of safety) offers the potential for substantial recovery of channels that could be used to support demand for service within the VHF aviation spectrum.

3.2.4 Controller-Pilot Data Link Communications (CPDLC)

The objective of CPDLC is to provide a data messaging capability between controllers and pilots that will reduce voice frequency congestion and provide a more precise and efficient means of communicating instructions and requests. CPDLC begins with the creation and initiation of a message by a controller or pilot. CPDLC messages are ATN compliant, which accommodates message prioritization. Fixed or free-text messages are supported. In the 2015 time frame CPDLC will transition from a limited message set capability via a VDL-2 commercial network to a full message set capability that supports prioritization via the FAA VDL-3 network.

In the 2015 time frame the NAS Architecture projects the use of VDL-3 for CPDLC. Our link analysis has determined that a single VDL-3 sub-channel can conservatively support 4.8 kbps of data. Our communication load analysis identifies load requirements by domain as indicated in Table 3.2-9. The data in Table 3.2-9 is developed by adding the uplink and downlink for each domain in Table 4.5-6

Table 3.2-9 CPDLC Communication Load Requirements (kilobits per second)

	Airport	Terminal	En Route
CPDLC- Domain	6.3	2.2	2.4
CPDLC – (Estimate per Sector)	1.6 (4)	0.3 (7)	0.1 (20)

The above table indicates that a single VDL-3 sub-channel will easily support the single-sector loading projections for 2015. We recommend that the AATT CSA maintain the NAS Architecture approach for CPDLC.

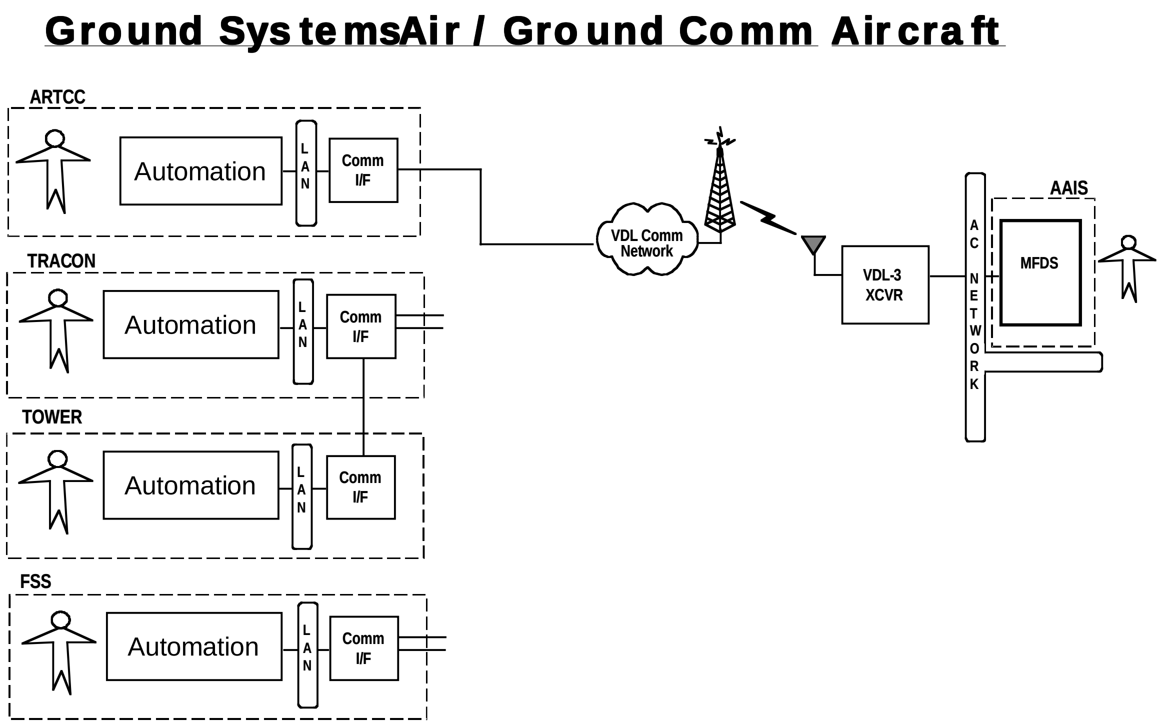

Figure 3.2-5 CPDLC Controller/Pilot Data Link Communications in 2015

The CPDLC communication links are shown in Table 3.2-10.

Table 3.2-10 CPDLC Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories (including Hazardous Weather Alerts)	CPDLC			✓						
✓ Acceptable Alternative		☐ NAS Architecture				★ Restricted Operation				

Technology Gap

There are no technology gaps identified for CPDLC via VDL-3.

3.2.5 Decision Support System Data Link (DSSDL)

As we establish the NAS-Wide Information System and promote the exchange of common data among participating nodes of the NAS, a data exchange method must be created that allows aircraft to participate as if they were "ground-based" nodes (i.e., they would have the same access and integrity of information as ground nodes). This is the objective of DSSDL. DSSDL provides a capability for the transfer of data between aircraft avionics and ATC automation (or other aircraft). Its purpose is to accommodate real time exchange of data that does not require human intervention or acknowledgement. The data transferred by DSSDL supports calculations by DSS algorithms that will be used by controllers and pilots to make decisions. Initially, this data exchange is not fully automated in that the controller or pilot must authorize its use by the aircraft DSS/ATC DSS, which is similar to the exchange and use of pre-departure clearance data today. In time, however, with system experience and the acceptance of controllers and pilots, DSSDL will become a fully automated method of negotiating/notifying change among participating nodes of the NAS. Figure 3.2-6 depicts the major elements of DSSDL.

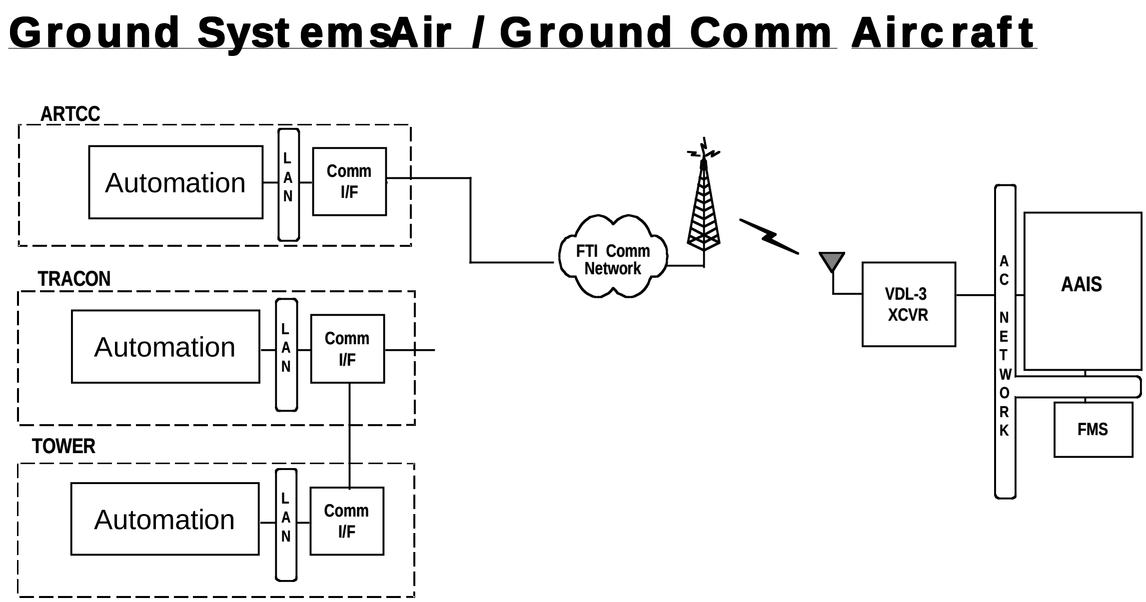

Figure 3.2-6 Decision Support System Data Link in 2015

Examples of DSSDL aircraft data include preference data for arrival time, meter fix, turbulence avoidance, approach/runway, performance data such as weight or trajectory change (route deviation warnings), and flight plan change requests. Examples of DSSDL ATC data are local TFM constraints and expected near term constraint changes.

DSSDL provides the data to DSS tools that are used to support the negotiation of preferred trajectories between pilots and controllers. As such, aircraft avionics and controller workstations must be designed to maintain workloads at a comfortable level, while ensuring that the decision-making process is timely and intuitive.

DSSDL preferences that result in clearance changes (i.e. flight plan or trajectory updates) will be provided to the aircraft via CPDLC message. For example, an aircraft preference for turbulence avoidance eventually may result in an ATC originated CPDLC message to CLIMB TO (*level*).

DSSDL is applicable only to aircraft that have an advanced FMS that supports integration with an onboard data link. Initial DSSDL messages most likely will be aircraft-to-ATC only, indicating preferences for routes or arrival times.

ASSUMPTIONS

- Only aircraft with avionics that allow integration of data link information into the flight management system can use DSSDL
- Data can be processed directly by ATC automation or aircraft avionics, but the results must be accepted by controller/pilot prior to use by automation in air traffic control or flight operations.
- DSSDL is an essential service.

The DSSDL communication links in 2015 are shown in Table 3.2-11.

Table 3.2-11 DSSDL Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Aircraft exchange performance / preference data with ATC to optimize decision support	DSSDL			✓	✓		✓	✓		✓
✓ Acceptable Alternative		☐ NAS Architecture				★ Restricted Operation				

It should be noted that while Mode-S and UAT also have data link capability that theoretically could be used to support DSSDL, they are not ATN compliant and are not recommended.

Our link analysis has determined that a single VDL-3 sub-channel can conservatively support 4.8 kbps of data. Our communication load analysis identifies load requirements for DSSDL in the 2015 time frame by domain as indicated in Table 3.2-12.

Table 3.2-12 DSSDL Communication Load Requirements (kilobits per second)

	Airport	Terminal	En Route
DSSDL – Domain	0.45	0.24	0.12
DSSDL – (Estimated by Sector)	0.12 (4)	0.03 (7)	0.01 (20)

The table above indicates that a single VDL-3 sub-channel will easily support the DSSDL loading projections for 2015. We recommend that the AATT CSA maintain the NAS Architecture approach for DSSDL.

Technology Gap

The following items require further definition in order to implement a DSSDL capability. These areas are currently under study by the FAA so they are not included in the gaps addressed in Task 10/11.

- Ground automation that can accept data input via direct data link and allow controller authorization
- Protocols that support routing and prioritization
- Data integrity / error correction algorithms
- Avionics that can accept data input via direct data link and allow pilot authorization

3.2.6 Automated Dependent Surveillance-Broadcast (ADS-B)

ADS-B aircraft continuously broadcast their position, velocity, and intent information using GPS as the primary source of navigation data to enable optimum maneuvering. ADS-B will support both air-ground and air-air surveillance. The major operational environments improved by ADS-B include “gap-filler” surveillance for non-radar areas, surface operations, pair-wise maneuvers, and approach/departure maneuvers. ADS-B equipped aircraft with CDTI equipment will provide enhanced visual acquisition of other ADS-B equipped aircraft to pilots for situational awareness and collision avoidance. Pilots and controllers will have common situational awareness for shared separation responsibility to improve safety and efficiency. When operationally advantageous, pilots in ADS-B equipped aircraft may obtain approval from controllers for pair-wise or approach/departure maneuvers. In the future, en route controllers in centers with significant radar coverage gaps will provide more efficient tactical separation to ADS-B equipped aircraft in non-radar areas. The received ADS-B surveillance data will enable controllers to “see” ADS-B equipped aircraft and reduce separation standards in areas where they previously used procedural control. The end-to-end connectivity diagram for ADS-B is shown in Figure 3.2-7**.**

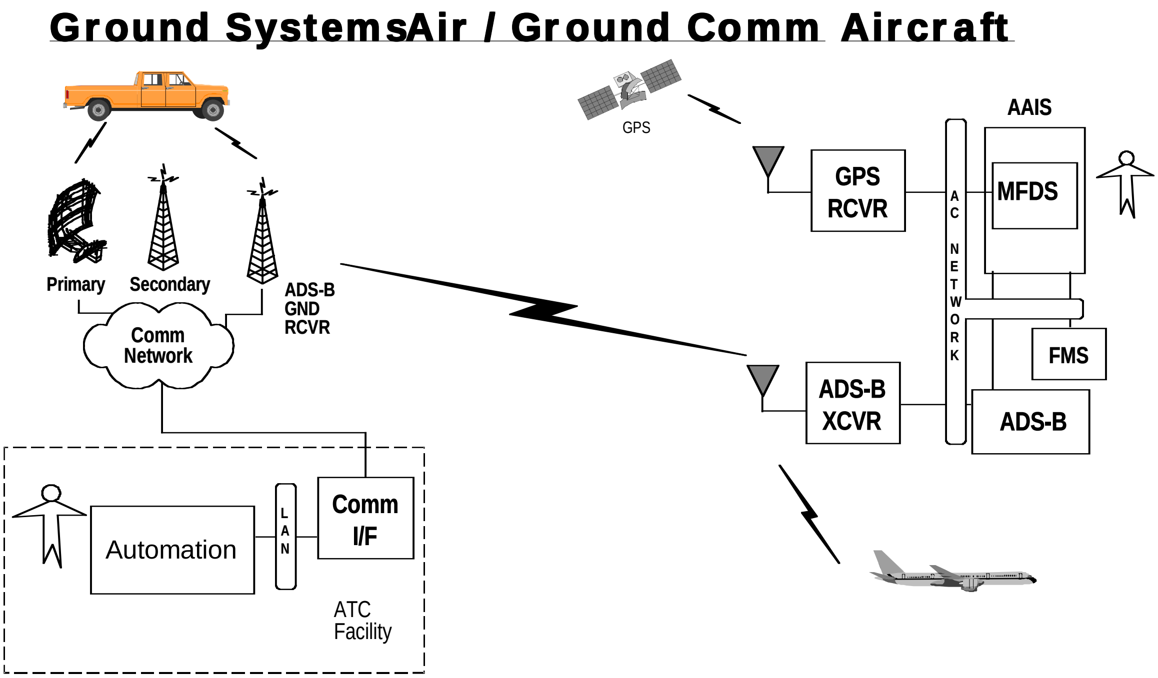

Figure 3.2-7 ADS-B Connectivity Diagram in 2015

ADS-B messages containing identification, state vector, intent, status and other information are assembled by aircraft avionics. ADS-B equipped aircraft broadcast the assembled messages over the ADS-B link twice per second (worst case) for reception by other ADS-B equipped aircraft or ATC ground stations. ADS-B equipped aircraft receive the messages over an air-air communication link, process the data, and display it on the cockpit display for improving situational awareness of the pilot. The aircraft automation function processes the intent and track data for other aircraft, performs collision management, and displays traffic and DSS information to the pilot to support air-air operations such as pair-wise maneuvers and collision avoidance.

ATC ground stations receive messages from ADS-B equipped aircraft over the air-ground communication link, process the messages, and send them to the responsible ATC facility. ADS-B and other primary and secondary surveillance data are processed by ATC automation along with ADS-B intent data to provide controllers with the necessary displays and controls to perform separation assurance and other ATC services. The ADS-B message content is consistent with the MASPS for ADS-B (RTCA/DO-242). ADS-B messages are designed to be flexible and expandable to accommodate potential ADS-B applications that are not yet designed. The surveillance data portion of an ADS-B message is used to support tactical and advisory ATC services, while the intent and other portions of an message supports more strategic services such as traffic synchronization.

While the emphasis in this architecture is on ADS-B, Automatic Dependent Surveillance - Addressable (ADS-A) is used in the oceanic domain and other remote areas such as Alaska. ADS-A will provide surveillance of intercontinental flights in oceanic airspace using a HF data link or satellite communications. Aircraft equipped with future navigation systems such as FANS-1A or ATN avionics will exchange information such as identification, flight level, position, velocity, and short-term intent with ADS-A ground equipment in oceanic Air Route Traffic Control Centers. Ground equipment and automation will display the aircraft position and track to oceanic controllers that will allow current oceanic lateral and longitudinal separation standards to be reduced for properly equipped aircraft. Additionally, controller will permit aircraft pairs equipped with ADS-B avionics to perform pair-wise maneuvers such as in-trail climbs or descents in selected oceanic airspace.

As part of the NAS Architecture, ADS-B will be deployed in a phased approach consistent with aviation community needs, FAA priorities, and projected budgets. In general, for each ADS-B operational environment, experiments and prototype demonstrations conducted as part of Safe Flight 21 lead to operational key site deployments. Key site deployments represent the increment where operational procedures and certified systems are used to deliver daily service. Following key site deployment, additional “pockets” of ADS-B will be deployed on a benefits-driven basis. These deployments eventually could result in national deployment. In the 2007 time frame initial deployment will be started for the “pocket” areas. Much of the initial ADS-B deployment will enable air-to-air use of ADS-B in selected airspace to demonstrate operational feasibility and achievement of estimated benefits. The extent of aircraft equipage and demand from the aviation community will be a factor in determining the strategy for deployment of ADS-B ground stations.

Our communication load analysis for ADS-B is shown in Table 3.2-13 and Section 4.6. Note that ADS-B is broadcast to all aircraft and ground stations within the range of the transmitter, so the communication requirement is not domain specific.

Table 3.2-13 ADS-B Communication Load Requirements (kilobits per second)

	Airport	Terminal	En Route	Total
ADS-B	16.1	3.3	1.5	20.9

In the airport domain, it is also necessary to consider surface vehicles such as baggage trucks, fuel trucks, snow plows, etc. If there are 75 moving vehicles broadcasting once per 1.1 seconds and 150 stationary vehicles broadcasting every ten seconds, the communication load increases to 28 kbps. Besides exceeding the capacity of some links, this load could produce clutter on the displays. Development of an approach for handling ADS-B at the airport should undergo research.

The ADS-B communication link options are shown in Table 3.2-14. The FAA is engaged in a program to evaluate three candidate ADS-B technologies (Mode-S Squitter, UAT, VDL-4) with a link decision expected in 2001. 1090 MHz Extended Squitter is derived from existing Secondary Surveillance Radar (SSR) Mode-S technology. This technology operates on a single frequency (i.e., 1090 MHz) operating at a data rate of 1 Mbps shared with other secondary surveillance radar users. Baseline ICAO standards for

1090 MHz extended squitter exist and RTCA/EUROCAE standards are under development, as well as updates to the existing ICAO standards.

Table 3.2-14 ADS-B Communication Link Options

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Aircraft continously broadcast their position and intent to enable optimum maneuvering	**ADS-B**				✓		✓	✓		
✓ Acceptable Alternative		☐ NAS Architecture			★ Restricted Operation					

Universal Access Transceiver (UAT) is a technology developed by the Mitre Corporation supporting both uplink and downlink broadcast services. UAT would operate on an as-yet-undetermined single dedicated frequency near 1000 MHz (966 MHz is being used for test purposes) at a data rate of 1 Mbps. UAT has been selected as the ADS-B technology in the Alaskan CAPSTONE initiative. Initiation of UAT standards development by RTCA is currently under consideration.

VDL Mode 4 is a technology operating on multiple dedicated VHF channels with a nominal data rate of 19.2 kbps per channel. VDL Mode 4 employs time division multiple access with both a self-organizing mode and a ground managed mode. VDL Mode 4 standards currently are under development by ICAO and EUROCAE.

The FAA, in close cooperation with the aviation community and international organizations, is working to define the operational concepts for ADS-B, evaluate the three candidate ADS-B link technologies, and plan for the transition to ADS-B in the NAS. The most important factor in the successful implementation of ADS-B is the Link Technology Decision scheduled for 2001. The goal is to have a single global ADS-B technology. This goal may not be achieved, but global standards for ADS-B technologies must be developed so ADS-B aircraft can operate both in CONUS and internationally. The Link Technology Decision could result in a combination of the ADS-B technologies. The ADS-B communication links used in the 2007 to 2015 time frame will depend on the link decision.

Technology Gap

A potential ADS-B technology gap is the human factors for display of ADS-B aircraft. A human factors study should be performed to define the symbology and content of controller and pilot displays. The symbology should indicate the source and quality of the positional data to support different operations and separation standards for normal or degraded operations.

Another potential gap is the availability of ADS-B communication avionics compatible with the technology or combination of technologies that result from the Link Technology Decision. Standards are already in work for the three potential ADS-B technologies. There could be additional work to define integrated standards if a combination of ADS-B technologies is selected.

As described above, an environment in which many vehicles are reporting, such as an airport, is likely to stress the system. Any solution must make it possible for any aircraft in the airport environment to see any ground or airborne vehicle, without presenting "noise" to aircraft at higher altitudes. Using separate frequencies for airborne and surface vehicles is a potential solution, but fails to help the pilot on a low visibility final approach where a surface vehicle (including a landed aircraft) is approaching a runway. The CDTI might be able to filter out non-threatening vehicles, this would help with visual clutter, but not help RF congestion. Use of lower power emitters or signal polarization might serve to limit the broadcasting range of surface vehicles. Research would help in being able to engineer a solution.

3.2.7 Airline Operational Control Data Link (AOCDL)

Aircraft Operational Control (AOC) – Pilot/Aircraft – AOC data exchange supports efficient air carrier/air transport operations and maintenance. The AOC's prime responsibility is to ensure the safety of flight and to operate the aircraft fleet in a legal and efficient manner. The AOC's business responsibility requires that the dispatcher conduct individual flights (and the entire schedule) efficiently to enhance the business success and profitability of the airline. Most major airlines operate a centralized AOC function at an operations center that is responsible for worldwide operations. Typical AOC data exchange supports airline operations (OOOI, flight data, position reporting, etc.) and maintenance (performance, diagnostic, etc.) Figure 3.2-8 depicts the major elements of AOCDL. The AOCDL communication links are shown in Table 3.2-15.

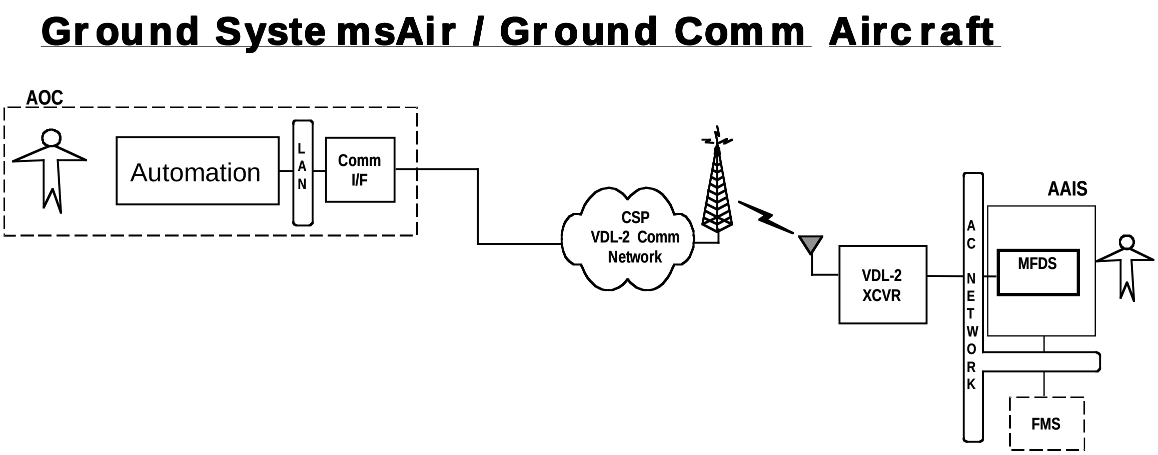

Figure 3.2-8 AOC Data Link in 2015

ASSUMPTION

A majority of current ACARS users will have migrated to VDL-2 use by 2007.

Table 3.2-15 AOCDL Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Pilot - AOC data exchange supports efficient air carrier/air transport operations and maintenance	AOCDL		✓					✓		✓
✓ Acceptable Alternative		NAS Architecture		AATT CSA Recommendation						

In the 2015 time frame, the AOC data link has become a significant part of the collaborative decision making process between ATC, AOC, and the aircraft. Our communication loading analysis for AOCDL by domain is shown in Table 3.2-16.

Table 3.2-16 AOCDL Communication Load Requirements (kilobits per second)

	Airport	Terminal	En Route	Total
AOCDL	8.8	9.1	3.7	
Worst Case	35.2 (4) [1]	9.1 (1)	3.7 (1)	48

Note: (X) is domain multiplier

Our communication load analysis, summarized in Table 3.2-16, projects peak loading for AOCDL from 3.7 – 9.1 kbps. Because frequency assignments for AOCDL are not based on domain (although volume of messages is), it is necessary to consider the communication load generated in a worst case area, such as one including en route airspace, a consolidated TRACON, and four airports. This environment requires 48 kbps. The current plan for AOCDL is to use four 25kHz frequencies to support AOCDL. Each frequency when used in a VDL-2 mode provides an effective data rate of 19.2 kbps. Thus we can expect 76.8 kbps from four channels. This is sufficient to support the projected demand in any environment in 2007. This merits more detailed analysis, since only four VDL-2 channels are expected to support the AOCDL communications load and the CPDLC/DSSDL loads as mentioned earlier; this combined load would require a capacity of 51.2 kbps. Once the transition to VDL-3 for data communications begins the CPDLC/DSSDL load on VDL-2 will decrease, providing capacity for continued AOCDL growth. Additionally, more AOC frequencies can be allocated to VDL Mode 2 to further increase capacity. Our projected demand justifies serious consideration of other high performance communication links, most especially SATCOM. Costs for two-way SATCOM service may be attractive for the AOCs if it is coupled with some form of APAXS that make it cost competitive with VDL-2.

Technology Gap

Given our projections for communications loading it is likely that some of the channels may operate near saturation. Research should be conducted to establish a means to sense channel overload and provide for a controlled degradation of service. There are no technology gaps for implementation of AOC data link via VDL-2. Technology gaps would exist however, should implementation over another communication link be chosen. Use of satellite communication links requires the demonstration of aeronautical mobile technologies for antenna, receivers, link algorithms, protocols, and standards. A major technology focus for broadband communications services is the need to provide more bandwidth (with a focus on Ka-band). Given the migration to these frequencies, the need exists for higher efficiency transmitters (both space and terrestrial), more adaptive bandwidth versus power efficient modulation, forward error correction coding (including turbo codes and bit/modulation symbol interleaving), and much expanded use of variable bit rate formats and dynamic multiplexing techniques such as asynchronous transfer mode (ATM) based technologies. Antennas and receivers must be adapted for the aviation market (size, weight, cost) and must overcome the problems of rain attenuation.

3.2.8 Automated Meteorological Transmission (AUTOMET)

AUTOMET definition is currently under the auspices of the RTCA SC 195 which has developed Minimum Interoperability Standards (MIS) for Automated Meteorological Transmission (RTCA DO-252) for wind, temperature, water vapor and turbulence. Conceptually, aircraft participating in an AUTOMET service program must be able to respond to AUTOMET commands issued by a ground-based command and control system. Downlink message parameters (e.g., frequency, type, etc) are changed by uplink commands from the ground-based systems and are triggered by various conditions (agreed to in advance by the airline, service provider and NWS), or by a request from an end user. Goals of the AUTOMET system are: 1) Increase the amount of usable weather data that is provided to the weather user community; 2) Increase the resolution of reports, forecast products and hazardous weather warnings to make providers of weather information more operationally efficient; 3) Increase the knowledge of the state of the atmosphere and decrease controller workload by automatically transmitting hazardous weather conditions to the ground and other aircraft to improve the ATC system.

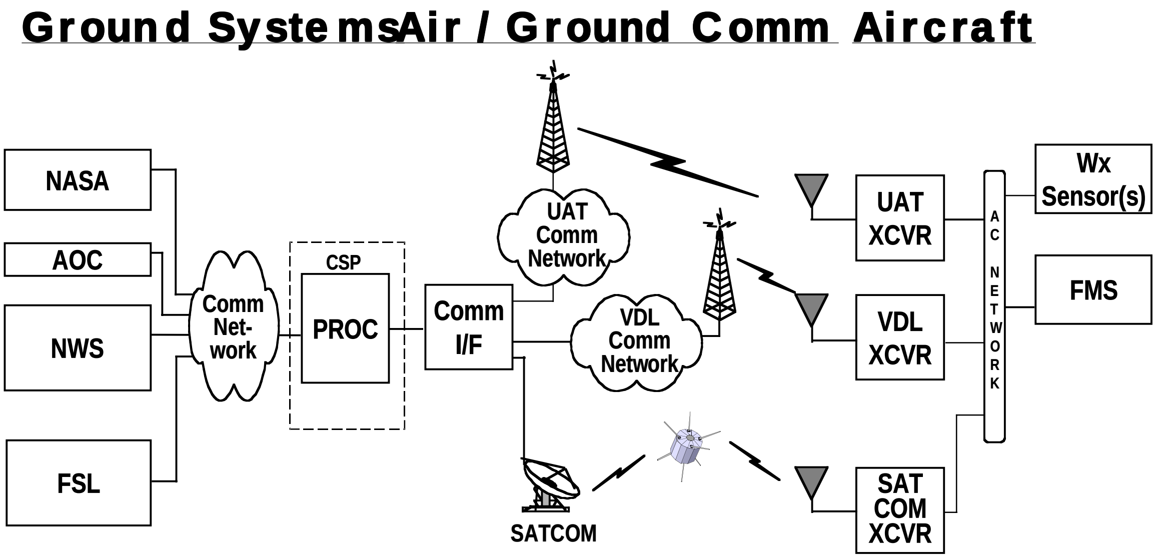

Figure 3.2-9. Automated Meteorological Transmission (AUTOMET) in 2015

The AUTOMET communication links are shown in Table 3.2-17. For aircraft weather reporting using AUTOMET, a number of aircraft collect wind, temperature, humidity, and turbulence information in flight and automatically relay the information to a commercial service provider using VDL Mode 2. The service provider collects and reformats the information and then forwards the information to the National Weather Service (NWS). The NWS uses this AUTOMET information and weather data from other sources to generate gridded weather forecasts. The improved forecasts are distributed to airlines and the FAA to assist in planning flight operations. The gridded weather data, based on AUTOMET data, is also provided to WARP for use by FAA meteorologists and used by several ATC decision support system tools to improve their predictive performance.

Table 3.2-17 AUTOMET Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Aircraft report airborne weather to improve weather nowcasting/forecasting	AUTOMET		✓					✓		✓
✓ Acceptable Alternative		☐ NAS Architecture								

Our communication loading analysis for AUTOMET is shown in Table 3.2-18 for each domain. The data in this table indicates that the downlink of all potential AUTOMET products in all domains could potentially saturate the capacity of a VDL-2 channel (19.2 kbps) in conjunction with other messages on the link. In all likelihood AUTOMET data will be downlinked on whatever data link is used to support AOCDL. Thus, if both AOCDL and AUTOMET are combined, the capacity of VDL-2 may be exceeded. methods to filter or compress the amount of data sent to the ground to limit the probability of saturating the VDL-2 channel may be needed. If AOCDL moves to SATCOM, however, there will be sufficient capacity to handle all projected AUTOMET data. As AUTOMET is mainly focused on GA aircraft though a move to SATCOM would bring with it the technology gaps associated with SATCOM.

Table 3.2-18 AUTOMET Communication Load Requirements (kilobits per second)

	Airport	Terminal	En Route	Total
AUTOMET	N/A	4.4	6.2	
Worst Case	N/A	4.4 (1)	6.2 (1)	10.6

Note: (X) is domain multiplier

Technology Gap

With the potential gaps notes above, from an air/ground communications standpoint, work is currently underway to develop standards for the implementation of AUTOMET. From an avionics perspective, further research could be performed to develop a sensor package that requires no calibration by the pilot or aircraft owner. It is essential to ensure that the data delivered from an AUTOMET sensor be accurate at all times in order to maintain the integrity of the forecast model.

3.2.9 Aeronautical Passenger Services (APAXS)

Passengers enjoy in-flight television, radio, entertainment, telephone, and Internet services. Our analysis of communication trends indicates that there will be a commercial demand for real-time television, radio, and Internet service to airline passengers and corporate travelers on business jets. Industry surveys have shown that while prerecorded programs and movies are a lower priority for passengers than reading, sleeping, and working, there always has been a high interest in live television. One service provider had surveys conducted that indicated 50% of respondents were interested, and 35% would be willing to pay $3-5 per flight for live television—the principal interest being in Cable News Network (CNN). This demand for service most likely will be satisfied through digital, high-data-rate satellite channels—most likely in the Ka-band. Figure 3.2-10 depicts the major elements of APAXS.

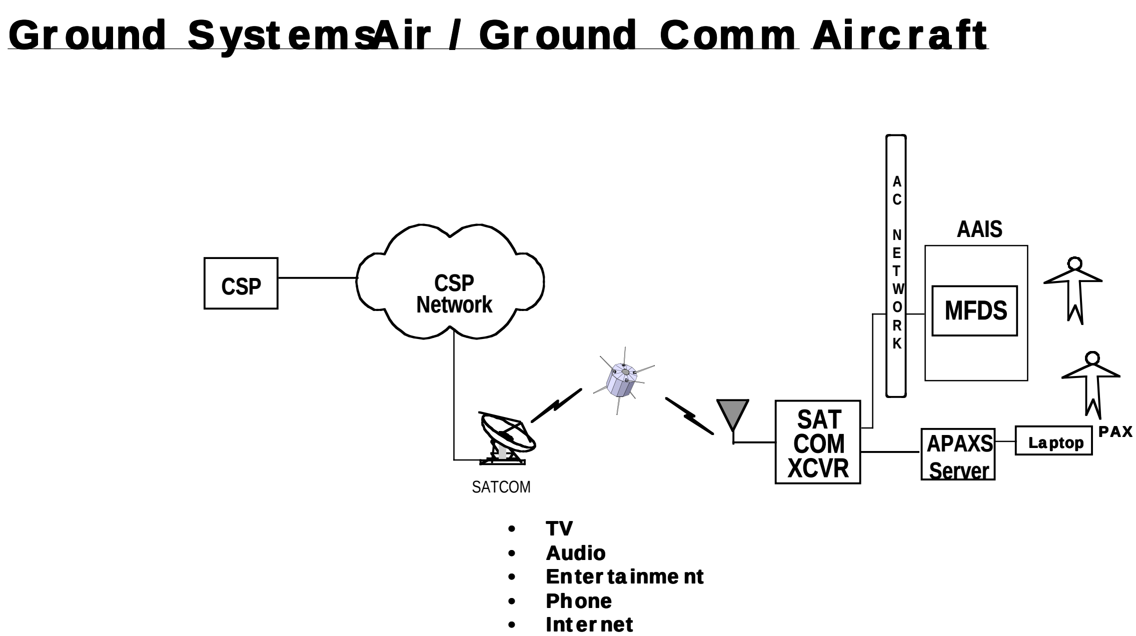

Figure 3.2-10. Aeronautical Passenger Services in 2015

ASSUMPTION

Commercial demand will drive satellite service for the aircraft.

While APAXS is not a service associated with any air traffic management function, it is likely that commercial demand will have driven direct broadcast satellite service to be available in the cabin. This availability is particularly important to note since it may provide an opportunity to support air traffic services that would not be possible otherwise. The APAXS communication links are shown in Table 3.2-20. Note, there are no plans for this in the current NAS architecture.

Table 3.2-19 APAXS Load Analysis Results (kilobits per second)

	En Route Uplink	En Route Downlink
APAXS – Domain	132	116
APAXS – CONUS	2635	2311

Table 3.2-20 APAXS Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Passengers enjoy in-flight television, radio, telephone, and internet service	APAXS								✓	✓
✓ Acceptable Alternative		☐ NAS Architecture				★ Restricted Operation				

Accordingly, we recommend that further study be conducted to determine the possibility for innovative partnerships or incentives that may leverage the involvement of commercial service providers in the delivery of selected air traffic services. For example, providers of broadcast entertainment channels to aircraft could be required to provide an air traffic services channel that is freely accessible by all aircraft. This example is similar to the requirement that cable television providers have with respect to public access channels.

A freely accessible high-data-rate channel could be used to provide FIS and TIS (strategic only) for all aircraft operating in the CONUS region.

Technology Gap

Suitable antenna/receiver design to resolve rain attenuation and provide a suitable (cost, size, weight) solution for all aircraft types.

3.3 2015 Communication System Architecture Link Alternatives Summary

This section provides a summary of the communication links that can be available to support the 2015 CSA. Each link is described in detail in Section 5 of this document and is summarized below in Table 3.3-1.

Table 3.3-1. Capacity Provided by Various Communication Links

Data Link	Single Channel Data Rate	Capacity for Aeronautical Communications	Channels Available to Aircraft	# Aircraft Sharing Channel (Expected Maximum)	Comments
	kbps	Channels	Channels	Aircraft	
HFDL	1.8	2	1	50	Intended for Oceanic
ACARS	2.4	10	1	25	ACARS should be in decline as users transition to VDL Mode 2
VDL Mode 2	31.5	4+	1	150	System can expand indefinitely as user demand grows
VDL Mode 3	31.5*	~300	1	60	Assumes NEXCOM will deploy to all phases of flight
VDL Mode 4	19.2	1-2	1	500	Intended for surveillance
VDL – B	31.5	2	1	Broadcast	Intended for FIS
Mode-S	1000**	1	1	500	Intended for surveillance
UAT	1000	1	1	500	Intended for surveillance/FIS
SATCOM	-	-	-	-	Assumes satellites past service life
Future SATCOM	384	15	1	~200	Planned future satellite
Future Ka Satellite	2,000	~50	~50	~200	Estimated capability - assumes capacity split for satellite beams
Fourth Generation Satellite	>100,000	>100	>100	Unknown	Based on frequency license filings

* Channel split between voice and data.
** The Mode-S data link is limited to a secondary, non-interference basis with the surveillance function and has a capacity of 300 bps per aircraft in track per sensor (RTCA/DO-237).

A summary of the peak communication loads for 2015 is provided in Table 3.3-2.

Table 3.3-2. Summary of Peak Communication Loads for 2015 (kbps)

2015	Airport Uplink	Airport Downlink	Terminal Uplink	Terminal Downlink	En Route Uplink	En Route Downlink
FIS	0.2	0.0	0.9	0.0	6.9	0.0
TIS	23.7	0.0	7.0	0.0	20.5	0.0
CPDLC	3.4	2.9	1.3	0.9	1.1	1.3
DSSDL	0.2	0.3	0.1	0.2	0.1	0.1
AOC	0.4	8.4	0.6	8.5	0.2	3.5
ADS Reporting	0.0	16.1	0.0	3.3	0.0	1.5
AUTOMET	0.0	0.0	0.0	4.4	0.0	6.2
APAXS	0.0	0.0	0.0	0.0	131.7	115.5

The NAS requires a data exchange capability that supports the establishment of an air-ground information base. The purpose of establishing and maintaining this information base is to provide the foundation for common situational awareness that in turn will provide the environment for efficient, collaborative, decision making. The technical concepts that support this information base are FIS, TIS, ADS-B and AUTOMET. Taken individually, a solution for each of these concepts could be developed from one of the individual links identified in Table 3.3-1. When viewed from a systems perspective, however, the notion of an integrated data exchange capability begins to emerge. This data exchange capability does not currently exist and the integrated need is not currently recognized in the NAS Architecture. The candidate links that could meet this need are in the initial stages of deployment or design. These are UAT and SATCOM respectively (although SATCOM would not support ADS-B).

Table 3.2-5 provides an overview of UAT and SATCOM. One potential advantage of using UAT would be that the majority of aircraft would already have a UAT radio (if it is the technology chosen for ADS-B) and a UAT terrestrial network would have been established. Additionally, UAT avionics have been designed to support all classes of aircraft. An advantage of SATCOM would be the wide area access provided without the need for a terrestrial network. Implementation of UAT should consider the use of dedicated channels and protocols for ADS-B and TIS in order to optimize their performance while FIS and AUTOMET could employ a more standard broadcast scheme.

The NAS also requires a data message exchange capability to support the efficient coordination of information, decision making, and the delivery of instructions. The technical concepts that support this are AOCDL, DSSDL, and CPDLC. The implementation of VDL-3 will more than adequately accommodate the ATC needs of 2015 and beyond.

3.4 Recommended 2015 AATT Communication System Architecture

In 2015 the physical AATT Communication System Architecture will consist of a communications link that supports continuous data exchange between the aircraft and ground. Additionally, a virtual air-ground communications network that routes message data over the most efficient path will also be available. In this time frame, all aircraft will be equipped with multimode radios that are capable of supporting data and voice communication via VDL-3. Aircraft will continue to downlink airborne weather information to NWS using the most economical communications path. Finally, some commercial aircraft will be equipped with SATCOM-based passenger service links that provide broadcast television, audio, and 2-way telephone and Internet capabilities for a service charge. A summary of the links is provided in Table 3.4-1.

Table 3.4-1 2015 AATT Technical Concepts to Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM- Broadcast	SATCOM- 2way
Aircraft continuously receive Flight Information to enable common situational awareness	**FIS**					✓		✓	✓	
Aircraft continuously receive Traffic Information to enable common situational awareness	**TIS**					✓		✓	✓	
Controller - Pilot Communication	**CPC**	✓		✓						
Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories (including Hazardous Weather Alerts)	**CPDLC**			✓						
Aircraft exchange performance / preference data with ATC to optimize decision support	**DSSDL**			✓						
Aircraft continously broadcast their position and intent to enable optimum maneuvering	**ADS-B**				✓		✓	✓		
Pilot - AOC data exchange supports efficient air carrier/air transport operations and maintenance	**AOCDL**		✓					✓		✓
Aircraft report airborne weather to improve weather nowcasting/forecasting	**AUTOMET**		✓					✓		✓
Passengers enjoy in-flight television, radio, telephone, and internet service	**APAXS**								✓	✓
✓ Acceptable Alternative		NAS Architecture		AATT CSA Recommendation						

In this time frame, the primary method of voice communication in the NAS is via VDL-3 with VHF-AM being used only in limited low-density airspace. The Class 1 user continues to receive flight information via VDL-B or SATCOM, with voice reporting as a backup over the VDL-3 link from a flight service specialist or an air traffic controller.

A majority of Class 1 aircraft are equipped with ADS-B avionics that transmit their derived position via the selected link (Mode-S, VDL-4, or UAT), which allows pilots to receive extended flight following and separation services due to the extended coverage of the ADS-B receiver network. Flight and traffic information is provided through UAT or SATCOM.

Class 2 users and Class 1 users differ in that some Class 2 users have access to AOCDL that provides operations and maintenance data via VDL-2. Additionally, in this time frame, the majority of Class 2 users will be equipped with a multimode radio that supports VDL-3 voice communications. Flight and traffic information is provided through UAT or SATCOM. Some Class 2 users may provide passenger services via SATCOM as well.

The Class 3 users see the greatest change in communications from the 2007 time frame. Virtually all Class 3 aircraft will be equipped with multimode radios that support controller-pilot voice and data communications via VDL-3. In addition, these aircraft will exchange performance and preference data with ATC via VDL-3 DSSDL. Flight and traffic information is provided through UAT or SATCOM. Two-way SATCOM will be available to support passenger Internet services and may begin to support aircraft-AOC and aircraft-ATC data exchange.

Class 3 aircraft will be the majority users of ADS-B via the selected link (Mode-S, VDL-4, or UAT) due to the maneuvering benefits derived from equipage. HFDL will continue to be used by some aircraft to support oceanic operations.

An overview diagram of the 2015 AATT Architecture alternative using broadband satellite is shown in Figure 3.4-1 and a terrestrial broadband alternative is depicted in Figure 3.4-2.

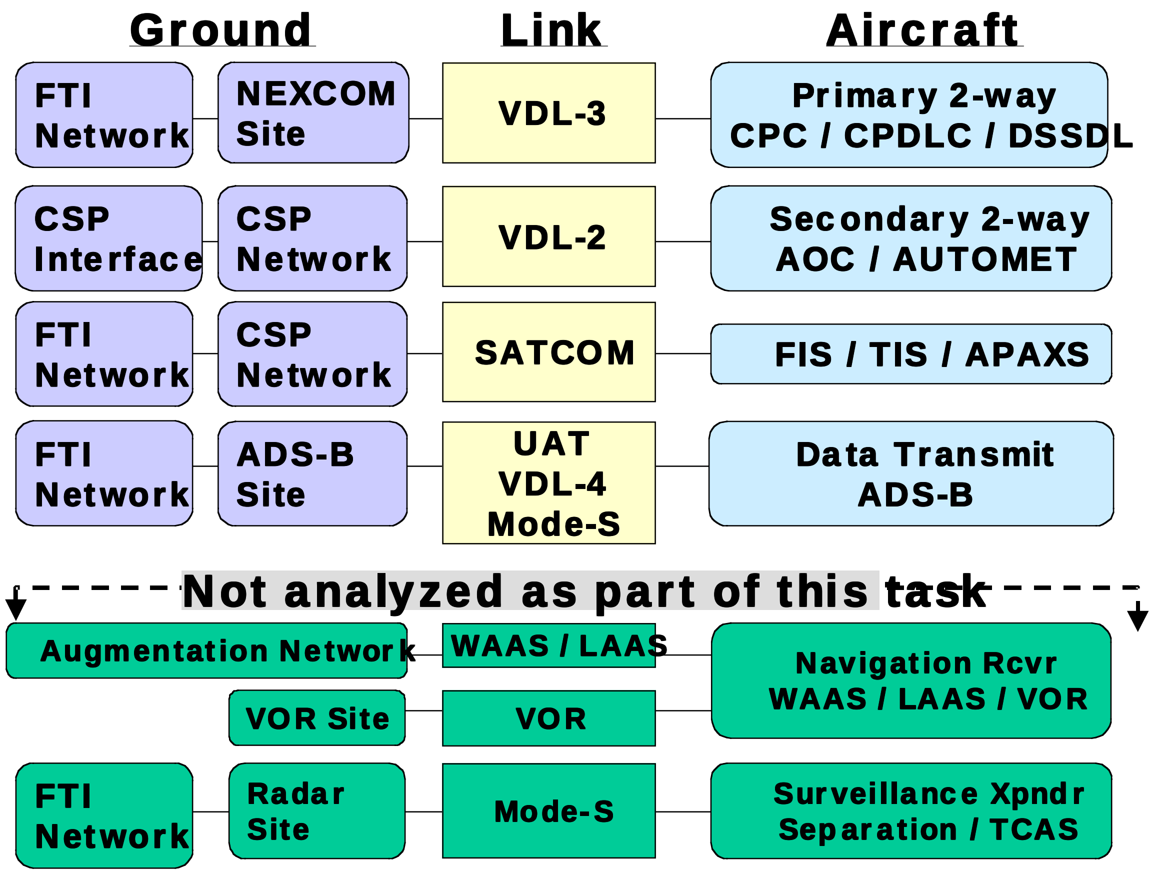

Figure 3.4-1. 2015 AATT Architecture Alternative - SATCOM Based

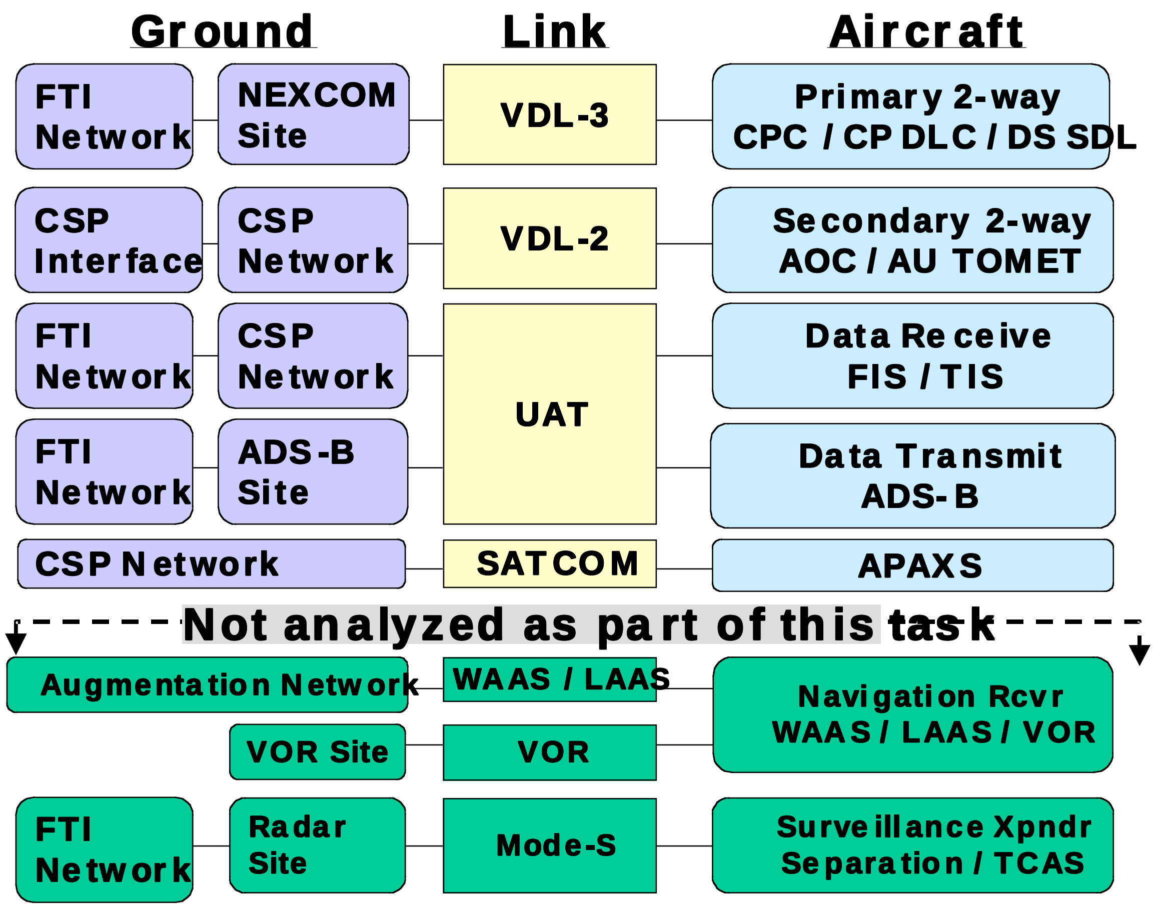

Figure 3.4-2. 2015 AATT Architecture Alternative - Terrestrial Based

There will continue to be a need to maximize the communication capacity of VHF data links operating in the protected aviation spectrum. Accordingly, we recommend further research in the areas of link modulation and data compression to increase the overall bit transfer rate, network prioritization schemes that combine voice and data, and the development of designs for virtual air ground links that will maximize the use of available frequencies.

Finally, the use of SATCOM will be driven by the commercial industry desire to provide high-data-rate services to passengers such as real time television and Internet. Air Traffic Service providers should stay aware of these efforts and look for opportunities to exploit this method of data transmission.

Accordingly, we recommend that further study be conducted to determine the possibility for innovative partnerships or incentives that may leverage the involvement of commercial service providers in the delivery of selected air traffic services via SATCOM. For example, providers of broadcast entertainment channels to aircraft could be required to provide an air traffic services channel that is freely accessible by all aircraft. This example is similar to the requirement that cable television providers have with regard to providing public access channels.

4 Communication Loading Analysis

4.1 Air-Ground Communications

The overall approach to the air-ground communications load analysis is illustrated in Figure 4.1-1 and presented in detail in the following sections. Air-ground communications service requirements are addressed in Section 4.2. Air-ground messages and messages per flight are calculated in Section 4.3. Voice message traffic per flight is calculated in section 4.4. Projections for the peak number of flights in 2015 and the total traffic load are calculated in Section 4.5. Section 4.6 addresses air-to-air message traffic.

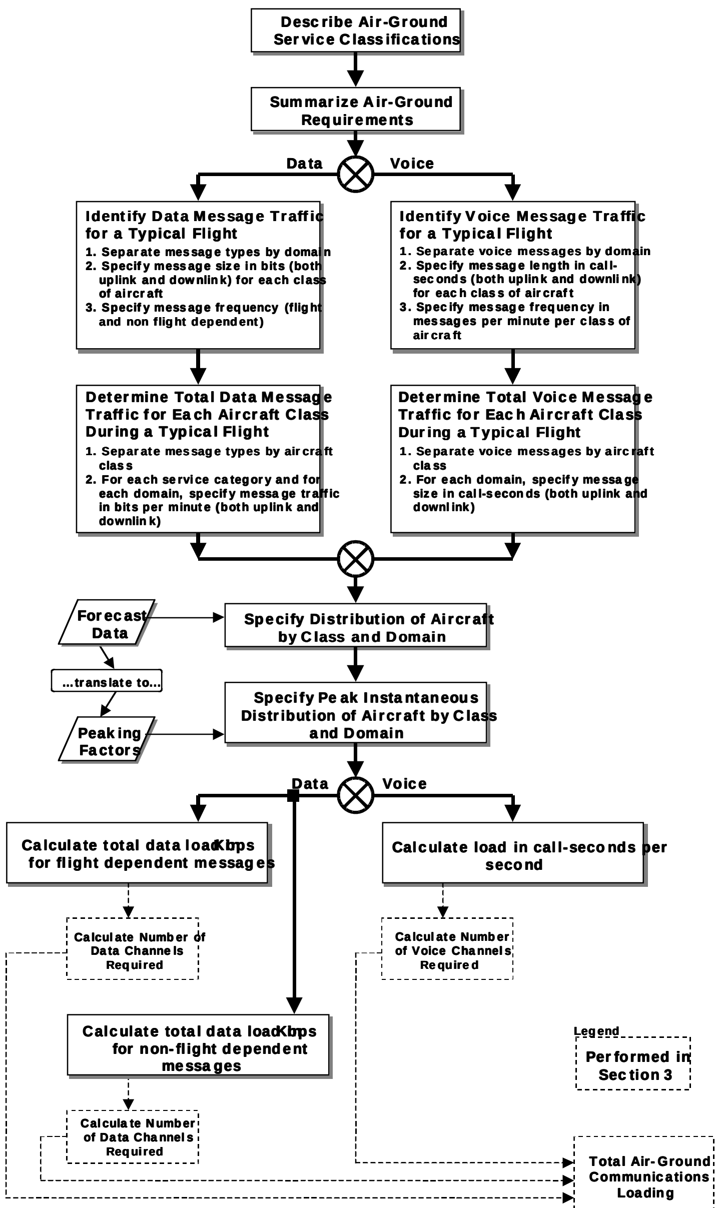

Figure 4.1-1. Communications Load Analysis Method

In this analysis, the term air-ground is used when the direction of the transmission is not relevant. Whenever direction is important, the terms uplink (ground-to-air) and downlink (air-to-ground) are used. The terms message and message traffic are used when the distinction between voice and data messages is not important. Otherwise, the term voice message or data message is used.

All message traffic is assigned to one of nine technical concept categories to simplify calculations and to provide insights that guide the architectural solutions presented in Chapter 3. The technical concept categories are shown in Table 4.1-1 and represent logical groupings of message types based on application and similar communications service requirements.

Table 4.1-1 Air-Ground Technical Concept Classifications

Category.	Technical Concept	Description of Concept
1	Flight Information Services (FIS)	Aircraft continually receive Flight Information to enable common situational awareness
2	Traffic Information Services (TIS)	Aircraft continuously receive Traffic Information to enable common situational awareness
3	Controller-Pilot Data Link Communications (CPDLC)	Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories (including Hazardous Weather Alerts)
4	Controller Pilot Communications (CPC) Voice	Controller - Pilot voice communication
5	Decision Support System Data Link (DSSDL)	Aircraft exchange performance / preference data with ATC to optimize decision support
6	Airline Operational Control Data Link (AOCDL)	Pilot - AOC messaging supports efficient air carrier/air transport operations and maintenance
7	Automated Dependent Surveillance (ADS) Reporting	Aircraft continuously transmit data on their position and intent to enable optimum maneuvering
8	Automated Meteorological Reporting (AUTOMET)	Aircraft report airborne weather data to improve weather nowcasting and forecasting
9	Aeronautical Passenger Services (APAXS)	Commercial service providers supply in-flight television, radio, telephone, entertainment, and internet service

Throughout the analysis, traffic is segregated by airspace domain and class of aircraft. The domains consist of airport, terminal, en route, and oceanic as defined in Table 4.1-2. By separating traffic loads according to domain, the air-ground communication architecture can be optimized to meet unique regional requirements. The three classes of aircraft are low-end general aviation (Class 1), high-end general aviation and commuter aircraft (Class 2), and commercial carriers (Class 3), as described in Table 4.1-3. The classification by domain and aircraft class gives a more precise traffic load estimate since the number, frequency, and type of message in many cases depends on where the aircraft is and what type of equipage it has. Table 4.1-4 shows the estimated aircraft population in each class that is equipped for a particular technical concept. The percentages in Table 4.1-4 were developed using FAA forecasts and engineering judgement. The values are only approximate but have been specified to the nearest percent to maintain internal consistency.

Table 4.1-2 Airspace Domains

Domain	Definition and Comment*
En route	Airspace in which en route air traffic control services are normally available. The average duration in this domain is 25 minutes per en route center.
Terminal	Airspace in which approach control services are normally available. The average duration in this domain is 10 minutes.
Airport	Airspace, including, runways and other areas used for taxiing, takeoff, and landing, in which tower control services are normally available. The average duration in this domain is 10 minutes.
Oceanic	Airspace over the oceans of the world, considered international airspace, where oceanic separation and procedures per the International Civil Aviation Organization are applied. The average duration in this domain is 180 minutes.

*Average duration of flights are taken from *Aeronautical Spectrum Planning for 1997-2010*, RTCA/DO-237, January 1997, p. F-4.

Table 4.1-3 Aircraft Classes

Class of Aircraft	Definition and Comment
Class 1	Operators who are required to conform to FAR Part 91 only, such as low-end General Aviation (GA) operating normally up to 10,000 ft. This class includes operators of rotorcraft, gliders, and experimental craft and any other user desiring to operate in controlled airspace below 10,000 ft. The primary distinguishing factor of this class is that the aircraft are smaller and that the operators tend to make minimal avionics investments.
Class 2	Operators who are required to conform to FAR Parts 91 and 135, such as air taxis and commuter aircraft. It is likely that high-end GA and business jets and any other users desiring to operate in controlled airspace will invest in the necessary avionics to be able to achieve the additional benefits.
Class 3	Operators who are required to conform to FAR Parts 91 and 121, such as Commercial Transports. This class includes passenger and cargo aircraft and any other user desiring to operate in controlled airspace. These users will invest in the avionics necessary to achieve the additional benefits.

Table 4.1-4 Percent of Aircraft Equipped for Each Technical Concept in 2015

Technical Concept	Class 1	Class 2	Class 3
FIS	52%	74%	79%
TIS	53%	65%	90%
CPDLC	48%	76%	98%
CPC (voice)	100%*	100%	100%
DSSDL	10%	34%	70%
AOCDL	N/A	5%	51%
ADS Reporting	53%	65%	90%
AUTOMET	52%	74%	79%
APAXS	2%	3%	46%

* Aircraft that are not equipped with a radio are excluded from the CSA.

4.2 Air-Ground Communications Service Requirements

General communications service requirements include priority, call setup time, latency, availability, restoration times, and NAS interfaces. Availability and restoration times depend on NAS priority level, which in turn drive the level of link redundancy needed. Table 4.2-1 shows requirements for each technical concept.

Table 4.2-1. Air-Ground Service Requirements

Technical Concept.	Priority	Availability Restoration Time	Call Setup Time	Latency End to End	Aircraft Interface
FIS	Routine	0.99 1.7 hour	≤10 sec	~10 sec	FAA NWIS Network
TIS	Critical, Essential	0.99999 6 seconds	≤ 5 sec	~1 sec	FAA Surveillance Network
CPDLC	Critical	0.99999 6 seconds	≤ 5 sec	~1 sec	FAA Air-Ground Com Network
CPC	Critical	0.99999 6 seconds	≤ 5 sec	~400 msec	FAA Air-Ground Com Network
DSSDL	Essential	0.999 10 minutes	≤ 5 sec	~1 sec	ATC Automation
AOCDL	Routine	0.99 1.7 hour	≤ 10 sec	~10 sec	Commercial Service Provider
ADS	Critical	0.99999 6 seconds	≤ 5 sec	~1 sec	Surveillance Network
AUTOMET	Routine	0.99 1.7 hour	≤ 30 sec	~10 sec	Commercial Service Provider
APAXS	Routine	0.99 1.7 hour	≤ 30 sec	~10 sec	Commercial Service Provider

The NAS System Requirements Specification defines priority levels as follows:

- Critical services are those which, if lost, would prevent the NAS from exercising safe separation and control of aircraft. For critical services the availability goal is 0.99999 and the goal for service restoral time is 6 seconds.
- Essential services are those which, if lost, would reduce the capability of the NAS to exercise safe separation and control of aircraft. For essential services the availability goal is 0.999 and the goal for service restoral time is 10 minutes.
- Routine services are those which, if lost, would not significantly degrade the capability of the NAS to exercise safe separation and control of aircraft. For routine services the availability goal is 0.99 and the goal for service restoral time is 1.68 hours.

Coverage requirements for air-ground services are assumed to be:

- Fully redundant coverage for continental United States (CONUS), Hawaii, Alaska, Caribbean islands, Canada, Mexico, and Central and South America.
- Single coverage over the Pacific and Atlantic Ocean regions (redundant coverage is assumed to be provided by other CAAs and by commercial service providers
- Single coverage over the polar regions

Voice traffic in 2015 is assumed to use digital links with a data rate of 4800 bits per second. This rate, in conjunction with a channel bit error rate (BER) of 10^{-5} after error correction, should be adequate to satisfy voice quality requirements. This BER is equivalent to a worst-case block error probability of 10^{-2} for each kilobit block and is assumed to be satisfactory for planned data services as well as digital voice service.

Oceanic communications requirements are somewhat relaxed from en route requirements. Availability for critical communications is assumed to be 0.9999 with a restoral time of 6 seconds and a message latency of 10 seconds.

These service requirements are used in the load analysis for purposes of grouping messages with similar service and delivery requirements. They are also used to select communications link technologies and develop of the overall architecture presented in Chapter 3. The latency requirement in Table 4.2-1, for example, would appear to preclude the use of geosynchronous satellites for critical voice services (CPC voice) due to satellite propagation delays, which exceed 200 milliseconds. Although latency is considered a “soft” requirement in this analysis, the architecture solution in Chapter 3 does not use geosynchronous satellites for CPC voice service because of the excessive propagation delay.

4.3 Air-Ground Data Message Traffic Requirements

Information on message sizes and frequencies came from a number of sources. A unique message identifier (Msg ID), shown in Table 4.3-1, is assigned to the various message types to simplify the analysis. In some cases, these message types represent specific messages with a fixed length and repetition rate. In general, however, message types are merely representative of the type and the characteristics are simply an average.

Table 4.3-1. Message Types and Message Type Identifiers

Message Type Identifier	Message Type
M1	ADS
M2	Advanced ATM
M3	Air Traffic Information
M4	Not used - See M43, M44
M5	Airline Business Support: Electronic Database Updating
M6	Airline Business Support: Passenger Profiling
M7	Airline Business Support: Passenger Re-Accommodation
M8	Airline Maintenance Support: Electronic Database Updating
M9	Airline Maintenance Support: In-Flight Emergency Support
M10	Airline Maintenance Support: Non-Routine Maintenance/ Information Reporting
M11	Airline Maintenance Support: On-Board Trouble Shooting (non-routine)
M12	Airline Maintenance Support: Routing Maintenance/ Information Reporting
M13	Arrival ATIS
M14	Not used - See M43, M44
M15	Convection
M16	Delivery of Route Deviation Warnings
M17	Departure ATIS
M18	Destination Field Conditions
M19	Diagnostic Data
M20	En Route Backup Strategic General Imagery
M21	FIS Planning – ATIS
M22	FIS Planning Services
M23	Flight Data Recorder Downlinks
M24	Flight Plans
M25	Gate Assignment

Message Type Identifier	Message Type
M26	General Hazard
M27	Icing
M28	Icing/ Flight Conditions
M29	Low Level Wind Shear
M30	Out/ Off/ On/ In
M31	Passenger Services: On Board Phone
M32	Pilot/ Controller Communications
M33	Position Reports
M34	Pre-Departure Clearance
M35	Radar Mosaic
M36	Support Precision Landing
M37	Surface Conditions
M38	TFM Information
M39	Turbulence
M40	Winds/ Temperature
M41	System Management and Control
M42	Miscellaneous Cabin Services
M43	Aircraft Originated Ascent Series Meteorological Observations
M44	Aircraft Originated Descent Series Meteorological Observations

Each message type is mapped to an aircraft class and airspace domain based on information in the reference source and expert knowledge. The messages are further assigned to technical concept categories to aid in the presentation of data and to simplify the communications architecture design process.

Some message types are extremely large and compression is required in order to reduce communications loads. The compression ratios assumed in this analysis are shown in Table 4.3-2. In some cases, the same message is sent with different compression ratios because the required resolution is not the same in all domains (e.g., M15 and M28). Note that all traffic loading data presented in this chapter has been compressed according to Table 4.3-2 and no further compression should be applied.

Throughout the analysis voice and data traffic are treated separately to deal with the unique requirements each imposes on the communications architecture.

Table 4.3-2. Data Compression Factors Used (1:1 assumed for all other messages)

Domain	Msg ID	Compression*
Terminal Tactical	M18 M20 M27 M29 M37	10:1 10:1 10:1 10:1 20:1
Terminal Strategic	M15 M28 M35	50:1 50:1 10:1
En Route Tactical	M39	50:1
En Route Near Term Strategic	M15 M26 M28 M37 M39	20:1 20:1 20:1 20:1 20:1

Domain	Msg ID	Compression*
En Route Far Term Strategic	M15 M26 M28	50:1 50:1 50:1

**Data Communications Requirements, Technology and Solutions for Aviation Weather Information Systems, Phase I Report, Aviation Weather Communications Requirements*, Lockheed Martin Aeronautical Systems

4.3.1 Data Message Traffic per Flight

Data message traffic tables are developed for each class of aircraft based on the particular set of messages required by that class in a given domain. Note that frequency units are expressed in terms of messages per flight or messages per minute per flight, depending on the nature of the communications. For messages that occur on a periodic basis and are independent of the number of aircraft, frequencies are expressed in terms of messages per minute. These non-flight dependent messages are listed in a separate table (see Table 4.3-6) and only added the total communications load after other calculations are completed. The largest common unit used to express message frequencies and flight times was a minute; this time unit was chosen as the basic unit for all calculations because it helps to distinguish between traffic loads channel data rates.

Data message traffic by flight for each class of aircraft is summarized in Table 4.3-3, Table 4.3-4, and Table 4.3-5. These tables do not represent peak traffic, but rather the expected traffic with departures and arrivals evenly distributed within each domain. All message sizes are expressed in bits.

Table 4.3-3. Data Message Traffic for Class 1 Aircraft (flight dependent)*

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)	Frequency	Downlink Size (bits)
FIS	M17	En Route	1 msg/flt	3200	1 msg/flt	64
	M21	Terminal	1 msg/flt	400	1 req/flt	56
	M22	Airport	1 msg/10 sec	2100	1 req/flt	64
	M22	Terminal	1 msg/10 sec	2000	6 req/flt	64
	M22	En Route	1 msg/10 sec	2000	4 req/flt	64
	M28	En Route	1 msg/flt	45000	N/A	N/A
CPDLC	M32	Airport	10 msg/flt	123	10 msg/flt	32
	M32	Terminal	9.6 msg/flt	123	13.1 msg/flt	32
	M32	En Route	10.2 msg/flt	118	17.4 msg/flt	34
	M34	Airport	1.25 msg/flt	1800	2.25 msg/flt	304
	M41	Airport	5 msg/flt	720	4 msg/flt	720
	M41	Terminal	2 msg/flt	720	1 msg/flt	720
	M41	En Route	6 msg/flt	720	5 msg/flt	720
DSSDL	M16	Airport	1 msg/5 flts	800	1 msg/5 flts	800
	M16	Terminal	1 msg/5 flts	800	1 msg/5 flts	800
	M16	En Route	1 msg/5 flts	800	1 msg/5 flts	800
	M2	Airport	1 msg/flt	40	1 msg/flt	960
	M2	Terminal	1 msg/flt	40	1 msg/flt	960
	M2	En Route	1 msg/flt	40	1 msg/flt	960
	M38	Airport	2 msg/flt	800	2 msg/flt	800
	M38	Terminal	1 msg/2 flt	800	1 msg/2 flt	100

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)	Frequency	Downlink Size (bits)
DSSDL	M38	En Route	1 msg/flt	800	1 msg/flt	100
ADS Reporting	M1	Airport	1 msg/flt	128	1 msg/1.1 sec	144
	M1	Terminal	1 msg/flt	128	1 msg/5.33 sec	144
	M1	En Route	1 msg/flt	128	1 msg/12.1 sec	144
AUTOMET	M14	Airport	N/A	N/A	10 msg/flt	430
	M14	Terminal	N/A	N/A	3 msg/minute	430
	M14	En Route	N/A	N/A	1 msg/15 minutes	430
	M4	Terminal	1 msg/flt	56	1 msg/5 minutes	1760
	M4	En Route	1 msg/flt	56	1 msg/5 minutes	1760
	M43	Terminal	1 msg/flt	56	3 msg/min	512
	M43	En route	1 msg/flt	56	1 msg/6 min	2152
	M44	En Route	1 msg/flt	56	1 msg/2min	3544

*Compressed per Table 4.3-2

Table 4.3-4. Data Message Traffic for Class 2 Aircraft (flight dependent)*

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)	Frequency	Downlink Size (bits)
FIS	M17	En Route	1 msg/flt	3200	1 msg/flt	64
	M21	Terminal	1 msg/flt	400	1 req/flt	56
	M22	Airport	1 msg/10 sec	2100	1 req/flt	64
	M22	Terminal	1 msg/10 sec	2000	6 req/flt	64
	M22	En Route	1 msg/10 sec	2000	4 req/flt	64
CPDLC	M32	Airport	10 msg/flt	123	10 msg/flt	32
	M32	Terminal	9.6 msg/flt	123	13.1 msg/flt	32
	M32	En Route	10.2 msg/flt	118	17.4 msg/flt	34
	M34	Airport	1.25 msg/flt	1800	2.25 msg/flt	304
	M41	Airport	5 msg/flt	720	4 msg/flt	720
	M41	Terminal	2 msg/flt	720	1 msg/flt	720
	M41	En Route	6 msg/flt	720	5 msg/flt	720
DSSDL	M16	Airport	1 msg/5 flts	800	1 msg/5 flts	800
	M16	Terminal	1 msg/5 flts	800	1 msg/5 flts	800
	M16	En Route	1 msg/5 flts	800	1 msg/5 flts	800
	M2	Airport	1 msg/flt	40	1 msg/flt	960
	M2	Terminal	1 msg/flt	40	1 msg/flt	960
	M2	En Route	1 msg/flt	40	1 msg/flt	960
	M38	Airport	2 msg/flt	800	2 msg/flt	800
	M38	Terminal	1 msg/2 flt	800	1 msg/2 flt	100
	M38	En Route	1 msg/flt	800	1 msg/flt	100
AOCDL	M10	Terminal	3 msg/flt	480	3 msg/flt	10400
	M11	Airport	6 msg/flt	480	6 msg/flt	10080
	M11	Terminal	6 msg/flt	480	6 msg/flt	10080
	M11	En Route	6 msg/flt	480	6 msg/flt	10080
	M12	Airport	3 msg/flt	480	3 msg/flt	10400
	M12	Airport	3 msg/flt	480	3 msg/flt	5200
	M12	Terminal	3 msg/flt	480	3 msg/flt	5200
	M12	En Route	3 msg/flt	480	3 msg/flt	10400
	M12	En Route	3 msg/flt	480	3 msg/flt	5200

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)	Frequency	Downlink Size (bits)
AOCDL	M19	Terminal	N/A	N/A	1 msg/min	50
	M19	En Route	N/A	N/A	1 msg/min	50
	M23	En Route	N/A	N/A	1 msg/flt	3000
	M25	Airport	1 msg/flt	10	1 msg/flt	10
	M30	Airport	1 msg/flt	10	1 msg/flt	10
	M30	Terminal	1 msg/flt	10	1 msg/flt	10
	M33	En Route	2 msg/flt	10	2 msg/flt	80
	M8	Airport	3 msg/flt	480	3 msg/flt	10400
	M8	Terminal	3 msg/flt	480	3 msg/flt	10400
	M8	En Route	3 msg/flt	480	3 msg/flt	10400
	M9	Terminal	1 msg/flt	2600	4 msg/flt	240
	M9	En Route	1 msg/flt	2600	4 msg/flt	240
ADS Reporting	M1	Airport	1 msg/flt	128	1 msg/1.1 sec	144
	M1	Terminal	1 msg/flt	128	1 msg/5.33 sec	144
	M1	En Route	1 msg/flt	128	1 msg/12.1 sec	144
AUTOMET	M14	Airport	N/A	N/A	10 msg/flt	430
	M14	Terminal	N/A	N/A	3 msg/minute	430
	M14	En Route	N/A	N/A	1 msg/15 minutes	430
	M4	Terminal	1 msg/flt	56	1 msg/5 minutes	1760
	M4	En Route	1 msg/flt	56	1 msg/5 minutes	1760
	M43	Terminal	1 msg/flt	56	3 msg/min	512
	M43	En route	1 msg/flt	56	1 msg/6 min	2152
	M44	En Route	1msg/flt	56	1 msg/2min	3544

*Compressed per Table 4.3-2

Table 4.3-5. Data Message Traffic for Class 3 Aircraft (flight dependent)*

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)	Frequency	Downlink Size (bits)
FIS	M17	En Route	1 msg/flt	3200	1 msg/flt	64
	M21	Terminal	1 msg/flt	400	1 req/flt	56
	M22	Airport	1 msg/10 sec	2100	1 req/flt	64
	M22	Terminal	1 msg/10 sec	2000	6 req/flt	64
	M22	En Route	1 msg/10 sec	2000	4 req/flt	64
	M28	En Route	1 msg/flt	45000	N/A	N/A
CPDLC	M32	Airport	10 msg/flt	123	10 msg/flt	32
	M32	Terminal	9.6 msg/flt	123	13.1 msg/flt	32
	M32	En Route	10.2 msg/flt	118	17.4 msg/flt	34
	M34	Airport	1.25 msg/flt	1800	2.25 msg/flt	304
	M41	Airport	5 msg/flt	720	4 msg/flt	720
	M41	Terminal	2 msg/flt	720	1 msg/flt	720
	M41	En Route	6 msg/flt	720	5 msg/flt	720
DSSDL	M16	Airport	1 msg/5 flts	800	1 msg/5 flts	800
	M16	Terminal	1 msg/5 flts	800	1 msg/5 flts	800
	M16	En Route	1 msg/5 flts	800	1 msg/5 flts	800
	M2	Airport	1 msg/flt	40	1 msg/flt	960
	M2	Terminal	1 msg/flt	40	1 msg/flt	960
	M2	En Route	1 msg/flt	40	1 msg/flt	960
	M38	Airport	2 msg/flt	800	2 msg/flt	800
	M38	Terminal	1 msg/2 flt	800	1 msg/2 flt	100
	M38	En Route	1 msg/flt	800	1 msg/flt	100

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)	Frequency	Downlink Size (bits)
AOCDL	M10	Terminal	3 msg/flt	480	3 msg/flt	10400
	M11	Airport	6 msg/flt	480	6 msg/flt	10080
	M11	Terminal	6 msg/flt	480	6 msg/flt	10080
	M11	En Route	6 msg/flt	480	6 msg/flt	10080
	M12	Airport	3 msg/flt	480	3 msg/flt	10400
	M12	Airport	3 msg/flt	480	3 msg/flt	5200
	M12	Terminal	3 msg/flt	480	3 msg/flt	5200
	M12	En Route	3 msg/flt	480	3 msg/flt	10400
	M12	En Route	3 msg/flt	480	3 msg/flt	5200
	M19	Terminal	N/A	N/A	1 msg/min	50
	M19	En Route	N/A	N/A	1 msg/min	50
	M23	En Route	N/A	N/A	1 msg/flt	3000
	M25	Airport	1 msg/flt	10	1 msg/flt	10
	M30	Airport	1 msg/flt	10	1 msg/flt	10
	M30	Terminal	1 msg/flt	10	1 msg/flt	10
	M33	En Route	2 msg/flt	10	2 msg/flt	80
	M8	Airport	3 msg/flt	480	3 msg/flt	10400
	M8	Terminal	3 msg/flt	480	3 msg/flt	10400
	M8	En Route	3 msg/flt	480	3 msg/flt	10400
	M9	Terminal	1 msg/flt	2600	4 msg/flt	240
	M9	En Route	1 msg/flt	2600	4 msg/flt	240
ADS Reporting	M1	Airport	1 msg/flt	128	1 msg/1.1 sec	144
	M1	Terminal	1 msg/flt	128	1 msg/5.33 sec	144
	M1	En Route	1 msg/flt	128	1 msg/12.1 sec	144
AUTOMET	M14	Airport	N/A	N/A	10 msg/flt	430
	M14	Terminal	N/A	N/A	3 msg/minute	430
	M14	En Route	N/A	N/A	1 msg/15 minutes	430
	M4	Terminal	1 msg/flt	56	1 msg/5 minutes	1760
	M4	En Route	1 msg/flt	56	1 msg/5 minutes	1760
	M43	Terminal	1 msg/flt	56	3 msg/min	512
	M43	En route	1 msg/flt	56	1 msg/6 min	2152
	M44	En Route	1msg/flt	56	1 msg/2min	3544
APAXS	M31	En Route	5 10-min/flt	1440000	5 10-min/flt	1440000
	M42	En Route	1 msg/flt	1000000	20 msg/flt	1000
	M5	En Route	3 msg/flt	5200	6 msg/flt	480
	M6	En Route	2 msg/flt	5200	2 msg/flt	480
	M7	En Route	2 msg/flt	5200	2 msg/flt	480

*Compressed per Table 4.3-2

Table 4.3-6. Non Flight Dependent Data Message Traffic (all aircraft classes)*

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)
FIS	M15	En Route	4 products/60 minutes	252000
	M15	En Route	6 products/60 minutes	306000
	M15	Terminal	6 products/60 minutes	252000
	M18	Terminal	60 products/60 minutes	1300
	M20	En Route	4 products/60 minutes	2800000
	M26	En Route	2 product/60 min	144000
	M26	En Route	6 products /60 min	350000

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)
FIS	M27	Terminal	60 products /60 min	5510
	M28	En Route	6 products /60 min	219000
	M28	En Route	2 products/60 min	27000
	M40	En Route	1 product/60 minutes	54000
	M40	En Route	6 product/60 minutes	262500
	M29	Terminal	6 products/60 min	480
	M35	Terminal	31 products/60 minutes	7350
	M37	En Route	4 products/60 minutes	28800
	M39	En Route	1 product/60 minutes	27000
	M39	En Route	6 product/60 minutes	131000
	M39	En Route	4 product/60 minutes	252000
TIS	M3	Airport	1 msg/2 sec	224
	M3	En Route	1 msg/6 sec	224
	M3	Terminal	1 msg/4.8 sec	224

*Compressed per Table 4.3-2; all downlink traffic is flight dependent and therefore excluded from this table

Non-flight dependent products usually are large messages that are identical for all recipients. They can be sent on a periodic basis and the number of times they are sent is not dependent on the number of flights. The message characteristics are assumed to be the same for all classes and domains, with the exception of TIS messages. The size of TIS messages varies depending on the number of aircraft being reported. The total communications load will therefore depend on whether the message is being transmitted nationwide or just to the aircraft in a small region.

4.3.2 Data Message Load Per Flight

In order to convert messages per flight to communications channel loading, several assumptions are required regarding the duration of flights, communications protocol overheads, and message characteristics:

- ATN protocol overheads are applied to all connection-oriented messages, i.e., CPDLC, DSSDL, AOCDL, and AUTOMET messages, plus flight dependent FIS messages.
- The ATN protocol network layer overhead varies according to message context and message size; the actual overhead spans a wide range of documented values. RTCA/DO-237, for example, uses a protocol overhead of 136% for uplink messages and 1376% for downlink messages. (These values are biased toward the maxima that can be expected; the average overhead on downlink traffic is likely to be far less in practice.) For very short messages (i.e., CPDLC), this analysis assumes an average uplink overhead of 100% and an average downlink overhead of 200%. For longer messages (i.e., all other ATN traffic), the average overhead is assumed to 20% in both directions. These assumptions are in general agreement with the results of ARINC overhead predictions for various AOC messages.
- Non-flight dependent FIS messages and all TIS messages include a network layer overhead of 10% for error detection and synchronization.
- A physical layer overhead of 50% is assumed on all connection-oriented data messages (RTCA/DO-237).
- Modulation efficiency for D8PSK is assumed to be 1.25 bps per Hertz (RTCA/DO-237).
- The average time a flight spends in each airport domain is 10 minutes (RTCA/DO-237).
- The average time a flight spends in each terminal domain is 10 minutes (RTCA/DO-237).
- The average time a flight spends in each en route domain is 25 minutes per center; an average flight spans two centers.

- The average time a flight spends in the oceanic domain is 180 minutes.
- Only AUTOMET message types M43 and M44 are included in the data communications loading calculations; these messages are assumed to contain all the information found in other AUTOMET messages and are larger in size. Message sizes and frequencies are based on the 1999 draft RTCA Minimum Interoperability Standard for AUTOMET.
- 8 bits per character is used to convert messages size in characters to message size in bits for AUTOMET messages M43 and M44; all other messages were expressed as bits in the source documents used.
- All AUTOMET traffic is suppressed in the airport domain to reduce channel requirements; the data is highly redundant and duplicates what is available from fixed airport weather sensors.

These assumptions are used to convert data message traffic in Tables 4.3-3, 4.3-4 and 4.3-5 into bits per flight per minute for each Technical Concept and class of aircraft. To get bits per minute per flight, the message size in bits is multiplied by the frequency in messages per minute times the proportion of aircraft equipped (Table 4.1-4). If the messages are on a per flight basis, the conversion requires multiplying the message size in bits times the number of messages per flight in a particular domain divided by the time a flight spends in that domain to obtain bits per minute per flight. This number is then multiplied by the proportion of aircraft equipped (Table 4.1-4) to arrive at the estimates shown in Table 4.3-7, Table 4.3-8, and Table 4.3-9.

Table 4.3-7. Data Message Traffic for Aircraft Class 1 (bits per min per flight)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	9434.9	4.8	9015.6	32.9	16419.7	9.6
CPDLC	815.6	671.2	301.9	196.9	254.5	289.7
DSSDL	25.9	39.2	8.6	16.8	5.8	7.0
AOCDL	N/A	N/A	N/A	N/A	N/A	N/A
ADS Reporting	6.8	4162.9	6.8	859.1	2.7	378.4
AUTOMET	N/A	N/A	4.2	1150.2	3.4	1595.4
APAXS	N/A	N/A	N/A	N/A	N/A	N/A

*Compressed per Table 4.3-2

Table 4.3-8. Data Message Traffic for Aircraft Class 2 (bits per min per flight)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	13426.6	6.8	12829.8	46.9	23366.5	13.6
CPDLC	1291.4	1062.7	478.0	311.7	403.0	458.7
DSSDL	88.1	133.2	29.4	57.3	19.6	23.9
AOCDL	52.0	997.2	70.6	1007.6	28.3	414.3
ADS Reporting	8.3	5105.5	8.3	1053.7	3.3	464.1
AUTOMET	N/A	N/A	6.0	1636.8	4.8	2270.4
APAXS	N/A	N/A	N/A	N/A	N/A	N/A

*Compressed per Table 4.3-2

Table 4.3-9. Data Message Traffic for Aircraft Class 3 (bits per min per flight)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	14333.8	7.3	13696.7	50.1	24945.3	14.6
CPDLC	1520.6	1313.8	616.4	401.9	519.7	591.5
DSSDL	100.8	193.5	60.5	117.9	40.3	49.2
AOCDL	530.2	10171.4	720.4	10277.9	288.5	4225.7
ADS Reporting	11.5	7069.1	11.5	1458.9	4.6	642.6
AUTOMET	N/A	N/A	6.4	1747.4	5.1	2423.8
APAXS	N/A	N/A	N/A	N/A	148255.2	130046.4

*Compressed per Table 4.3-2

4.3.3 Non Flight Dependent Data Message Traffic

The total number of FIS and TIS messages transmitted does not vary with the number of flights or the instantaneous airborne count. For these non-flight dependent messages, the message size in bits is multiplied by the frequency in messages per minute and listed separately in Table 4.3-10. Note that the length of a TIS message is directly proportional to the number of aircraft reporting in a local, regional, or national area, depending on the communications architecture assumed. The values in Table 4.1-4 (Percent of Aircraft Equipped for Each Technical Concept) are not used in this calculation since number of aircraft equipped to receive TIS messages does not affect the channel loading.

Table 4.3-10. Non-Flight Dependent Data Message Traffic (bits per min)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	N/A	N/A	38,154.1	N/A	391,695.3	N/A
TIS	7392.0/acft	6.2	3080.0/acft	6.2	2464.0/acft	2.5

*Compressed per Table 4.3-2

4.3.4 Oceanic Data Message Load Per Flight

In the oceanic domain, data message traffic includes en route messages plus certain messages unique to oceanic flights. It is assumed that users in 2015 will want to receive the full complement of en route messages in the oceanic domain, if the communications links can support it. Using the same messages and message frequencies in the oceanic domain would provide seamless communications when transiting the NAS. Table 4.3-11 is only presented for Class 3 aircraft since the other classes are used primarily for domestic flights.

Table 4.3-11. Oceanic Data Message Traffic for Aircraft Class 3 (bits per min per flight)*

Technical Concept	Airport		Terminal		Oceanic	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	N/A	N/A	N/A	N/A	6,912.0	0.0
CPDLC	N/A	N/A	N/A	N/A	361.6	515.8
DSSDL	N/A	N/A	N/A	N/A	6.7	8.5
AOCDL	N/A	N/A	N/A	N/A	47.0	865.9
ADS Reporting	N/A	N/A	N/A	N/A	1.0	41.5

Technical Concept	Airport		Terminal		Oceanic	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
AUTOMET	N/A	N/A	N/A	N/A	0.9	3,068.2
APAXS	N/A	N/A	N/A	N/A	40,260.0	40,032.0

*Compressed per Table 4.3-2

4.4 Voice Traffic

ATC voice traffic is not included with data message traffic even though it can be digitized and sent as a data message. This is because CPC voice communications are highly interactive and require immediate acknowledgement. For reasons of safety, ATC voice services must also meet stringent availability, reliability, and diversity requirements that exceed what is required for most data messages. The premium paid for this type of service dictates that its use be limited to critical communications. By 2015, it is assumed that terminal and en route voice communications to high-end aircraft will have transferred completely to CPDLC.

APAXS voice messages are routine and are not included in airport and terminal domains where it is assumed that on-board telephones must remain stowed for reasons of safety. Predicted passenger telephone calls are based on the assumption that 5% of the passengers place a 5 minute call in a one-hour period. The time is equally divided between uplink (listening) and downlink (talking) channels. For purposes of this analysis, only Class 3 aircraft are assumed to have passenger telephony. Note that voice traffic is expressed in call-seconds, i.e., the amount of time an uplink or downlink channel is in use.

Table 4.4-1. Voice Message Traffic in 2015 (call-seconds)

Message	Domain	Class	Uplink	Downlink	Msgs. per Flight
CPC Clearances	Airport	1	5 sec	5 sec	1/flt
CPC Clearances		1	5 sec	1 sec	2/flt
CPC Clearances		2	5 sec	5 sec	1/flt
CPC Clearances		2	5 sec	1 sec	2/flt
CPC Clearances		3	5 sec	5 sec	1/flt
CPC Clearances		3	5 sec	1 sec	2/flt
CPC Clearances	Terminal	1	5 sec	10 sec	1/flt
CPC TOC*		1	5 sec	5 sec	1/flt
CPC Advisories	En Route	1	20 sec	5 sec	1/flt
APAXS	En Route	1	150 sec	150 sec	0.05 passngr/hr

* Transfer of Communications

The total voice traffic per flight is calculated by multiplying the duration of the voice message by the number of times the message occurs and dividing by the time spent in the domain. The results are summed for each domain and class of aircraft to get the total per flight requirements.

Table 4.4-2. CPC Voice Message (call-seconds per min per flight)

Class	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
1	1.5 sec	0.7 sec	1.0 sec	1.5 sec	0.8 sec	0.2 sec
2	1.5 sec	0.7 sec	N/A	N/A	N/A	N/A
3	1.5 sec	0.7 sec	N/A	N/A	N/A	N/A

The APAXS passenger telephony calculations assume an average flight has 90 passengers and that 5% of the passengers in a given hour will talk for 150 seconds and listen for 150 seconds. Since the time spent in en route per flight is 50 minutes, the uplink and downlink load is 0.05 calls per passengers per hour x 90 passengers per flight x 5/6 hour per flight x 150 seconds per call / 50 minutes per flight = 11.3 call-seconds per minute per flight while en route.

Table 4.4-3. APAXS Voice Message (call-seconds per min per flight)

Class	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
3	N/A	N/A	N/A	N/A	11.3	11.3

4.5 Traffic Load Analysis

4.5.1 Flight Forecasts

The average traffic load is developed from the per flight message traffic multiplied by the expected number of flights in 2015. Communications links, however, are generally designed for peak loads to avoid increased delays or blocking when traffic is heaviest. Peak flights by domain for 1998 are therefore projected out to 2015 to estimate the peak load. The projections shown in Table 4.5-1 represent a 25% increase in operations between 1998 and 2015 for the aircraft classes of interest. FAA forecasts for terminal area itinerant aircraft operations are used because they correspond closely to the number of flights and are readily available from FAA forecast data by class of aircraft. For simplicity, it is assumed that the percent growth within each aircraft class and domain is the same as the percent growth in total aircraft operations.

Table 4.5-1. Peak Number of Flights (Aircraft) by Domain in 2015

Year	Operations*	Airport	Terminal	En Route
1998	73,169,228	154	110	400
2015	91,433,515	192	137	500

*APO Terminal Area Forecast Summary Report, TAF System Model

Applying the forecast distribution of operations for each class of aircraft to the number of flights in each domain provides the approximate distribution of flights by class and domain for 2015 as shown in Table 4.5-2.

Table 4.5-2. Estimated Peak Distribution of Flights by Class and Domain in 2015

Class	Operations*	Airport	Terminal	En Route
1	51,883,989	109	78	284
2	17,545,459	37	26	96
3	22,004,067	46	33	120
Total	91,433,515	192	137	500

*APO Terminal Area Forecast Summary Report, TAF System Model

4.5.2 Data Traffic Load

Multiplying the peak number of flights in Table 4.5-2 by the messages per flight in Table 4.3-7, Table 4.3-8, and Table 4.3-9 results in the estimated peak loads shown in Table 4.5-3, Table 4.5-4, and Table 4.5-5.

Table 4.5-3. Peak Data Message Traffic for Aircraft Class 1 in 2015 (kilobits per min)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	1,028.4	0.5	982.7	3.6	1,789.7	1.0
CPDLC	88.9	73.2	32.9	21.5	27.7	31.6
DSSDL	2.8	4.3	0.9	1.8	0.6	0.8
ADS Reporting	0.7	453.8	0.7	93.6	0.3	41.3
AUTOMET	N/A	N/A	0.5	125.4	0.4	173.9

*Compressed per Table 4.3-2

Table 4.5-4. Peak Data Message Traffic for Aircraft Class 2 in 2015 (kilobits per min)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	496.8	0.3	474.7	1.7	864.6	0.5
CPDLC	47.8	39.3	17.7	11.5	14.9	17.0
DSSDL	3.3	4.9	1.1	2.1	0.7	0.9
AOCDL	1.9	36.9	2.6	37.3	1.0	15.3
ADS Reporting	0.3	188.9	0.3	39.0	0.1	17.2
AUTOMET	N/A	N/A	0.2	60.6	0.2	84.0

*Compressed per Table 4.3-2

Table 4.5-5. Peak Data Message Traffic for Aircraft Class 3 in 2015 (kilobits per min)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	659.4	0.3	630.0	2.3	1,147.5	0.7
CPDLC	69.9	60.4	28.4	18.5	23.9	27.2
DSSDL	4.6	8.9	2.8	5.4	1.9	2.3
AOCDL	24.4	467.9	33.1	472.8	13.3	194.4
ADS Reporting	0.5	325.2	0.5	67.1	0.2	29.6
AUTOMET	N/A	N/A	0.3	80.4	0.2	111.5
APAXS	N/A	N/A	N/A	N/A	6,819.7	5,982.1

*Compressed per Table 4.3-2

Combining the peak data message load for each aircraft class and converting to kilobits per second gives the aggregate loads shown in Table 4.5-6. Here it is seen that APAXS and FIS account for most of the traffic load in 2015.

Table 4.5-6. Combined Peak Data Message Traffic for All Aircraft Classes in 2015 (kilobits per second)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	36.4	0.0	34.8	0.1	63.4	0.0
CPDLC	3.4	2.9	1.3	0.9	1.1	1.3
DSSDL	0.2	0.3	0.1	0.2	0.1	0.1
AOCDL	0.4	8.4	0.6	8.5	0.2	3.5
ADS Reporting	0.0	16.1	0.0	3.3	0.0	1.5
AUTOMET	N/A	N/A	0.0	4.4	0.0	6.2
APAXS	N/A	N/A	N/A	N/A	113.7	99.7

*Compressed per Table 4.3-2

Aggregate non-flight dependent traffic loads are shown in Table 4.5-7 for regional coverage and in Table 4.5-8 for national coverage. The two tables are different because uplink TIS message size increases according to the number of aircraft in the area of interest. Regional TIS message sizes are based on the peak number of aircraft that would be found in a given domain (the smallest region of interest). The TIS traffic in Table 4.5-7 is calculated by multiplying traffic in Table 4.3-10 by the peak domain traffic in Table 4.5-2. The results are divided by 60 x 1000 to express the load in kilobits per second. From this table it can be seen that the combined FIS and TIS en route peak load would require a 27.1 kbps uplink channel and the peak airport load would require a 23.7 kbps uplink channel.

Table 4.5-7. Regional Non-Flight Dependent peak Data Message Traffic for All Aircraft Classes in 2015 (kilobits per sec)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	N/A	N/A	0.6	N/A	6.5	N/A
TIS	23.7	0.0	7.0	0.0	20.5	0.0

*Compressed per Table 4.3-2

TIS message sizes in Table 4.5-8 for national coverage are based on estimates of the peak instantaneous airborne count for all domains. The peak instantaneous nationwide count in 2000 is roughly 5,500 aircraft. By 2015 it is assumed this will grow 25% to a total of 6,875 peak airborne aircraft. These aircraft are assumed to be distributed within the three domains in the same proportions found in Table 4.5-1, i.e., 1,595 in airport domains, 1,139 in terminal domains, and 4,142 in en route domains. Table 4.3-10 is multiplied by these flights to get the peak loads shown in Table 4.5-8. The table shows that nationwide (the largest area of interest), a TIS uplink channel has to carry 425 kilobits per second to meet peak loads. Approximately half of this load results from the combined operations of all airport domains.

Table 4.5-8. National Non-Flight Dependent Peak Data Message Traffic for All Aircraft Classes in 2015 (kilobits per sec)*

Technical Concept	Airport		Terminal		En Route		National
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink
FIS	N/A	N/A	0.6	N/A	6.5	N/A	7.1
TIS	196.4	0.0	58.5	0.0	170.1	0.0	425.0

*Compressed per Table 4.3-2

4.5.3 Oceanic Traffic Load

Peak oceanic flights are estimated based on peak hour contacts by Oakland and New York centers. Of the two, New York is slightly higher with 84 flights en route in the peak hour in 2000. Assuming 25% growth by 2015, the messages rates per flight in Table 4.3-11 are multiplied by 105 peak flights in 2015 and divided by 60 x 1000 to get kilobits per second. The table shows that a 12.8 kbps uplink and 7.9 kbps down link is sufficient for peak air traffic services, and a 70.5 kbps channel is sufficient in each direction for passenger services.

Table 4.5-9. Total Oceanic Data Message Traffic in 2015 (kilobits per second)*

Technical Concept	Airport		Terminal		Oceanic	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	N/A	N/A	N/A	N/A	12.1	0.0
CPDLC	N/A	N/A	N/A	N/A	0.6	0.9
DSSDL	N/A	N/A	N/A	N/A	0.0	0.0
AOCDL	N/A	N/A	N/A	N/A	0.1	1.5
ADS Reporting	N/A	N/A	N/A	N/A	0.0	0.1
AUTOMET	N/A	N/A	N/A	N/A	0.0	5.4
APAXS	N/A	N/A	N/A	N/A	70.5	70.1

*Compressed per Table 4.3-2

4.5.4 Voice Traffic Load

Peak CPC voice traffic is shown in Table 4.5-10. The number of call-seconds per minute per flight from Table 4.4-2 is multiplied by the peak number of flights in Table 4.5-2 and then divided by 60 seconds per minute to get channel occupancy in call-seconds per second. The total for each domain represents the number of full-period uplink or downlink analog voice channels required. To minimize the chance of all channels being in use at the same time, extra capacity can be added to the system. Assuming a multi-server queue with exponentially distributed call duration as a worst-case model for air-ground communications, the number of channels needed for a given probability of blocking can be calculated. In this analysis, it is assumed that there should be no more than one chance in five of finding all channels busy. Under peak traffic conditions with a 0.2 probability of all channels being busy, it is seen that the busiest airport domain in 2015 requires 8 voice channels. The busiest terminal domain requires 3 voice channels and the busiest en route domain requires 4 channels.

Table 4.5-10. Peak CPC Voice Messages in 2015 (call-seconds/second)

Class	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
1	2.7	1.3	0.7	0.7	2.0	0.5
2	0.9	0.4	0.3	0.3	0.2	0.1
3	1.2	0.5	0.0	0.0	0.0	0.0
Total	7.0		1.9		2.7	
Voice Channels Required (P=0.2)	8		3		4	

Peak passenger APAXS calls are estimated by multiplying the call-seconds per minute per flight in Table 4.4-3 times the peak number of flights in Table 4.5-2 (11.3 call-seconds per minute per flight x 120 en route flights = 1356 call-seconds per minute). This quantity is then divided by 60 seconds per minute to get channel occupancy in call-seconds per second as shown in Table 4.5-11. A multi-server queuing model is again used to calculate the number of voice channels needed for there to be no more than one chance in five that all channels are in use. The table shows that the peak passenger load in the busiest en route domain would require 39 voice channels. The total number of voice channels required nationwide might have approximately 10 times the traffic or 370 voice channels since other en route domains are below the peak en route domain and do not all peak simultaneously.

Table 4.5-11. Peak APAXS Voice Messages in 2015 (call-seconds/sec)

Class	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
3	N/A	N/A	N/A	N/A	22.6	22.6
Total	N/A		N/A		45.2	
Voice Channels Required (P=0.2)	N/A		N/A		39	

4.6 Air-Air Traffic

Air-to-air broadcasts originate from individual aircraft so the message load is directly proportional to the number of aircraft. It is assumed that aircraft originated data messages are for ADS-B surveillance applications, with minimal use of other applications proposed for ADS-B. From Table 4.5-6, it can be seen that the peak ADS-B traffic in the airport, terminal, and en route domains is 16.1 kbps, 3.3 kbps, and 1.5 kbps respectively. Postulating a “worst case” scenario where one aircraft is receiving ADS-B data from four airport domains, one terminal domain, and one en route domain (e.g., New York center), the total traffic would be 4 x 16.1 kbps plus 1 x 3.3 kbps plus 1 x 1.5, or 69.2 kilobits per second as the maximum required air-to-air link capacity in 2015. This represents approximately 532 ADS-B equipped aircraft on the ground or in the air that might be using an air-to-air link.

5 Networks, Standards, and Protocol Requirements

The recommended architecture includes the continuation of voice communication (with migration from analog to digital), data communication using ATN protocols, and broadcast communication using industry standard or proprietary protocols.

This section provides the technical detail of the data links available for the 2015 architecture. Much of this information also is presented in the Task 9 Report, *Characterize the Current and Near-Term Communications System Architectures,* which provides additional information on applications, standards, protocols, and networks. The links discussed in this section are:

- Analog Voice - DSB-AM
- Digital Voice
  - VDL Mode 3
  - Inmarsat-3
- Data Communication using the ATN
  - VHF Digital Link Mode 2 (VDLM2)
  - VHF Digital Link Mode3 (VDLM3)
  - Inmarsat-3
  - Inmarsat-4 (Horizons)
  - Other GEO Satellite Systems (e.g., Astrolink)
  - ICO Global (MEO system)
  - Iridium (LEO system)
  - ORBCOMM (LEO system)
  - High Frequency Data Link (HFDL)
- Ground-to-Air Broadcast Systems
  - VHF Digital Link Broadcast (VDL-B)
- Air-Air and Air-Ground Broadcast Systems
  - Mode-S
  - Universal Access Transceiver (UAT)
  - VHF Digital Link Mode 4 (VDLM4)

5.1 Standard Description Template

Each link is characterized according to section 4.6.1 of the Task Order and organized using the following template.

CHARACTERISTIC	Segment	DESCRIPTION
System Name		Name
Communication type	R/F Ground	HF, VHF, L-Band, SATCOM …
Frequency/Spectrum of Operations	R/F Ground	Frequency
System Bandwidth Requirement	R/F Ground	Bandwidth for channel and system
System and Channel Capacity	R/F	Number of channels and channel size
Direction of communications	R/F	Simplex, broadcast, duplex….
Method of information delivery	R/F Ground	Voice, data, compressed voice

CHARACTERISTIC	Segment	DESCRIPTION
Data/message priority capability	R/F Ground	High, medium, low
System and component redundancy	R/F Ground	
Physical channel characteristics	R/F	Line of sight (LOS), other
Electromagnetic interference	R/F	Text description
Phase of Flight Operations	Ground	Pre-flight, departure, terminal ….
Channel Data Rate	R/F Ground	Signaling rate
Robustness of channel and system	R/F	Resistance to interference, fading…
System Integrity	R/F Ground	Probability
Quality of service	R/F Ground	Bit error rate, voice quality
Range/coverage	R/F Ground	Oceanic, global, regional…
Link and channel availability	R/F Ground	Probability
Security/encryption capability	R/F Ground	Text description
Degree/level of host penetration	R/F	Percentage or class of users
Modulation scheme	R/F	AM, FM, D8PSK,….
Access scheme	R/F	CSMA, TDMA, ….
Timeliness/latency, delay requirements	R/F Ground	Delay
Avionics versatility	R/F	Application to other aircraft
Equipage requirements	R/F	Mandatory, optional
Architecture requirements	R/F Ground	Open System or proprietary
Source documents		References

Integrity is the ability of a system to deliver uncorrupted information and may include timely warnings that the information or system should not be used. Integrity is provided by the application, transport and network layers (rather than the link and physical layers) and is usually specified in terms of the probability of an undetected error. The integrity values in the following link descriptions thereby reflect service integrity requirements rather than "link integrity" requirements. The only meaningful measure of "link integrity" is a bit error rate, which is shown under quality of service.

Comm Link	System integrity (probability)
Voice DSB-AM	No integrity requirement for 2015 voice services
VDLM2	CPDLC and DSSDL will be ATN compliant services and require the end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message to be less than or equal to $10E^{-8}$ per message
VDLM3	No integrity requirement for 2015 voice services; ATN compliant services must meet an end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message to be less than or equal to $10E^{-8}$ per message
VDL-B	ATN compliant services must meet an end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message to be less than or equal to $10E^{-8}$ per message
Mode-S	ADS-B integrity is defined in terms of the probability of an undetected error in an ADS-B report received by an application, given that correct source data has been supplied to the ADS-B system. ADS-B system integrity is $10E^{-6}$ or better on a per report basis. [Note: Due to constraints imposed by the Mode S squitter message length, multiple messages must typically be received before all required data elements needed to generate a particular ADS-B report are available.]
UAT	ADS-B integrity is defined in terms of the probability of an undetected error in an ADS-B report received by an application, given that correct source data has been supplied to the ADS-B system. ADS-B system integrity is $10E^{-6}$ or better on a per report basis. Currently, the UAT worst-case overall undetected error probability for an ADS-B message is $3.7x10E^{-11}$, which exceeds the minimum requirement. [Note: For UAT, ADS-B messages map directly (one-to-one correspondence) to ADS-B reports; they are not segmented as they are in Mode S ADS-B).
Inmarsat-3	ATN compliant services must meet an end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message to be less than or equal to $10E^{-8}$ per message

Comm Link	System integrity (probability)
GEO Satellite	ATN compliant services must meet an end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message to be less than or equal to $10E^{-8}$ per message
MEO Satellite	ATN compliant services must meet an end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message to be less than or equal to $10E^{-8}$ per message
ICO Global Satellite	ATN compliant services must meet an end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message to be less than or equal to $10E^{-8}$ per message
Iridium Satellite	ATN compliant services must meet an end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message to be less than or equal to $10E^{-8}$ per message
HFDL	ATN compliant services must meet an end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message to be less than or equal to $10E^{-8}$ per message

5.2 Analog Voice

5.2.1 VHF DSB-AM

Most current ATC communication in the NAS is carried out using analog voice. Most of this communication uses double side-band amplitude modulation (DSB-AM) in the VHF Aeronautical Mobile (Route) Service band, using 25 kHz channels. Some military aircraft use UHF; controllers in oceanic sectors use a service provider for relaying HF messages to and from aircraft.

DSB-AM has been used since the 1940s, first in 100 kHz channels, then in 50 kHz channels. Recently, Europe has further reduced channel spacing to 8.33 kHz channels in some air space sectors due to their critical need for more channels. In the United States, the FAA provides simultaneous transmission over UHF channels for military aircraft. In the Oceanic domain beyond the range of VHF, aircraft use HF channels. Voice limits communications efficiency since the controller must provide all information verbally. Studies have shown that controller workload is directly correlated to the amount of voice communications required. Voice is subject to misinterpretation and human error and has been cited as having an error rate of 3% and higher. With the introduction of ACARS, AOC voice traffic dropped significantly although it is still used.

By 2015, most domestic sectors will have transitioned to digital voice using VDL-3, which will be mandatory in many classes of airspace. Although spectrum congestion is currently a problem, channel loading will cease to be a limiting factor as the busiest sectors are converted to VDL-3, which is more efficient than DSB-AM, and more pilot-controller communications will be conducted using data links instead of voice links.

Federal Air Regulations Part 91/JAR OPS 1.865 require two-way radio communications capability to operate an aircraft in class A, B, C or D airspace. Additionally, two-way radio communication is required to operate an aircraft on an Instrument Flight Plan in class E airspace. Two-way radio communication with ATC must be maintained continuously. ICAO has similar requirements.

Since many national authorities do not have current plans to implement VDL-3 for voice, aircraft that fly in international airspace probably will continue to need to use radios that support the current DSB-AM modulation, as well as 8.33 kHz channelization for parts of Europe.

Voice is necessary for the foreseeable future and is likely to continue as primary means of communication. Any changes in voice technology are likely to occur only with digital voice; and the legacy analog voice probably will continue unchanged.

Table 5.2-1. Analog Voice/VHF DSB-AM Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**Analog voice/VHF double sideband (DSB)—amplitude modulated (AM)**
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	Very High Frequency (VHF)
	Ground	Leased telephone channels
Frequency/ Spectrum of Operations	RF	117.975 MHz—137 MHz
System Bandwidth Requirement	RF	Nominal 3 kHz per channel with audio input 350 - 2,500 Hz 760 channels total in VHF band @ 25 kHz spacing/channel
	Ground	N/A
System and Channel Capacity (number of channels and channel size)	RF	Nominal 3 kHz per channel with audio input 350 - 2,500 Hz 760 channels total in VHF band @ 25 kHz spacing/channel System is constrained by frequency allocation, not technical limits. Expansion to 112 MHz has been discussed if radionavigation systems are decommissioned.
	Ground	Telephone line per assigned radio frequency
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Simplex - Transmission or reception on a single frequency but not simultaneously.
	Ground	Voice telephone lines are duplex
Method of information delivery (voice, voice recording, data, combination, etc.)	Avionics	Voice
	Ground	Voice
Data/message priority capability / designation (high, intermediate, low, etc.):	RF	N/A
	Ground	N/A
System and component redundancy requirement (1/2, 1/3, etc):	RF	Airborne - One unit required for GA, two units for air carrier. Redundancy: GA typically equips with two units (1:1); air carrier equips with three units (1:2).
	Ground	1:1 plus some overlap of ground stations
Physical channel characteristics (LOS, OTH, etc.):	RF	Line of Sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics:	RF	RTCA DO-160C, Sections 15, 18, 19, 20, and 21.
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	3 kHz
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	VHF channels are susceptible to terrain multipath but relatively robust and inherently resistant to fading, atmospheric attenuation, and weather.
System integrity (probability)	System	Voice communications are error prone and highly variable. An error rate of 3% has been measured in high activity sectors.
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	VHF voice communications are generally considered poor due to system and background noise. (The human ear is VERY good at puling voice out of a noisy AM signal.) A standard voice quality metric has not been applied.
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Range dependent on altitude: Maximum 250 nm at 30,000 feet 100 nm at 5,000 feet Coverage: United States including the Gulf of Mexico.
Link and channel availability	RF	Exceeds 99.7%

CHARACTERISTIC	SEGMENT	DESCRIPTION
Security/ encryption capability	RF	N/A
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	All commercial, all military and most GA aircraft equipped. All aircraft participating in IFR airspace are required to equip. Approximately 20,000 GA aircraft use only unrestricted airspace and do not equip with a radio.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Double sideband—Amplitude Modulation (DS-AM)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Normal signal propagation delay
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	System	Respond to 75% of calls within 10 seconds and 94% of calls within 60 seconds
	System	No measured data. Air Traffic Controllers determine access and priority based on traffic and situation.
Avionics versatility (applicability to other aircraft platforms)	Avionics	Any aircraft equipped with VHF transmitter and receiver.
Equipage requirements (mandatory for IFR, optional, primary, backup,	Avionics	Mandatory for IFR flight operations; not required in uncontrolled airspace.
	Ground	Ground stations required for coverage.
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications, etc.)	RF/Avionics	Signal in space characteristics are set by National and International standards. Avionics are developed by vendors with proprietary designs. Some integration with navigation.
	Ground	Vendors provide ground communications using proprietary hardware/software designs and commercial telecommunications standards.
Source documents		Annex 10, AERONAUTICAL TELECOMMUNICATIONS, ICAO; ARINC Quality Management Reports, Air/Ground Voice Performance

5.3 Digital Voice

The only available terrestrial network for digital voice is VDL Mode 3. As specified in ICAO Annex 10, Chapter 6, “VHF Air-Ground Digital Link,” VDL-3 uses the same modulation techniques as VDL Mode 2 and uses the same physical layer protocols with a few exceptions.

The VDL Mode 3 system is required to support a transparent, simplex voice operation based on a “Listen Before Push to Talk” channel access.

The ICAO “Manual on VHF Digital Link (VDL) Mode 3 Technical Specifications” requires that the vocoder “incorporate and default to the Augmented Multiband Excitation (AMBE) vocoder algorithm, version AMBE-ATC-10, from Digital Voice Systems, Incorporated (DVSI) for speech compression unless commanded otherwise.” A single specific algorithm is specified to achieve interoperability.

Technical characteristics for VDL Mode 3, which includes digital voice, are listed in the table below.

Table 5.3-1. VDL Mode 3 Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**Very High Frequency Digital Link Mode 3 (VDL Mode 3)**
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	Very High Frequency (VHF)
	Ground	Undetermined

CHARACTERISTIC	SEGMENT	DESCRIPTION
Frequency/ Spectrum of Operations:	RF	118-137MHz
System Bandwidth Requirement:	RF	25KHz/channel; Radios are specified for 112-137 MHz tuning range.
	Ground	Undetermined
System and Channel Capacity (number of channels and channel size):	RF	As a system, VDL Mode 3 can be used for all frequencies in the VHF aeronautical band, pending frequency sharing criteria. VDL Mode 3 is planned as the replacement for all current ATC analog voice frequencies, approximately 500 channels. Each VDL Mode 3 frequency provides four subchannels per 25KHz channel.
	Ground	Fractional T-1 interfaces indicated in draft specification.
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Simplex - Transmission or reception on a single frequency but not simultaneously, within a subchannel. Subchannels can communicate independently with TDMA scheme.
	Ground	Undetermined
Method of information delivery (voice, voice recording, data, combination, etc.):	RF	Pulse code modulated voice or data in any given subchannel
	Ground	Data, ATN-compliant network protocols
System and component redundancy requirement (1/2, 1/3, etc):	Ground	Undetermined, 1:1 is current practice.
	RF	Ground components: 1:1 is current practice Airborne: 1:2
Physical channel characteristics (LOS, OTH, etc.):	RF	Line Of Sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics	RF	DO-160D
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	VDL Mode 3 will begin deployment for voice function in approximately 2005 for En Route phase of flight. Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight will be added as the system expands.
Channel data rate (digital) and/or occupied band width (analog) requirement	RF	10,500 symbols/sec (3 bits per symbol) 31.5 Kbps/channel 4.8 Kbps/subchannel, 4 subchannels/channel
Robustness of channel and system (resistance to interference, fading, multipath, atmospheric attenuation, weather, etc.)	RF	VHF channels are susceptible to terrain multipath but relatively robust and inherently resistant to fading, atmospheric attenuation, and weather.
System integrity (probability)	System	Digital = BER of 10^{-3} for minimum, uncorrected signal BER of 10^{-6} daily average
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Voice: The PCM voice will be encoded using an 8 kHz sampling rate at a resolution of 16 bits per sample.
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Range dependent on altitude: Maximum 200 nm at 30,000 feet 80 nm at 5,000 feet Coverage: Implementation will begin in 2005 with U.S. En Route. Coverage will expand to all U.S. phases of flight.
Link and channel availability	RF	Radio availability =.99999
Security/ encryption capability	RF	No encryption at RF level. Should support ATN defined encryption and authentication at application level.
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	System is in implementation. Will be available to commercial, G/A, and military aircraft

CHARACTERISTIC	SEGMENT	DESCRIPTION
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Differential 8 Phase Shift Keying (D8PSK)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Time Division Multiple Access (TDMA)
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	< 250 msec
	System	< 250 msec
Equipage requirements (mandatory for IFR, optional, primary, backup, etc.)	Ground	Ground stations required for service/coverage.
	Avionics	NEXCOM will initially be deployed in analog voice Mode to allow fielding and aircraft equipage. When switched to digital voice Mode, approximately 2006, equipage will be mandatory for high En Route.
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)		Signal in space and protocols are defined by National and International standards. Ground equipment will be provided by vendors using proprietary designs. VDL data can support numerous applications.
Source documents		Implementation aspects for VDL Mode 3 system (version 2.0), VDL Circuit Mode MASPS and MOPS, Aeronautical Mobile Communications Panel (AMCP); Annex 10, AERONAUTICAL TELECOMMUNICATIONS, ICAO; RTCA /DO-224.

For satellite networks, which are operated by service providers rather than by national authorities, the SARPs specify vocoders selected by the service providers, subject to the AMCP validation process. Inmarsat uses several vocoders, depending on the specific service; the specifications are contained in Annex 10, Chapter 4. Specifications for vocoders for AMS(R)S using Next Generation Satellite Systems will be contained in technical manuals referenced by Annex 10, Chapter 12. No NGSS technical manuals have been approved yet.

At present, only Inmarsat provides satellite voice service satisfying the requirements of AMS(R)S. Iridium planned to provide AMS(R)S service for voice and data, but Iridium is no longer viable. Technical characteristics of the Inmarsat voice service are presented in the table below, along with data aspects of the Inmarsat-3 service.

Table 5.3-2. Inmarsat-3 Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**Inmarsat-3**
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	SATCOM – GEO satellite. Five satellites.
	Ground	Ground Earth Stations (GES)
Frequency/ Spectrum of Operations:		C Band ~ 4,000 to 8,000 MHz, and L Band ~1,000 to 2,000 MHz
System Bandwidth Requirement	RF	10 Mhz satellite 17.5 kHz for 21Kbps channel with A-QPSK modulation 10 kHz for 10.5 Kbps channel with A-QPSK 8.4 kHz for 8.4 Kbps channel with A-QPSK 5.0 kHz for 4.8 Kbps channel with A-QPSK 5.0 kHz for 2.4 Kbps channel with A-BPSK 5.0 kHz for 1.2 Kbps channel with A-BPSK 5.0 kHz for 0.6 Kbps channel with A-BPSK
	Ground	N/A
System and Channel Capacity (number of channels and channel size)	RF	Six channels per aircraft for Aero H (High) for current equipage Voice at either 9.6 kbps or 4.8 kbps Data at 10.5 - to 0.6 kbps Maximum voice capacity with additional aircraft equipment is 24 voice channels.
	Ground	N/A
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Complex - see Access scheme block
	Ground	Half Duplex
Method of information delivery (voice, voice recording, data, combination, etc.)	Avionics	Digitally encoded voice & data services
	Ground	Digitally encoded voice & data services
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	None - Pilot can seize voice channel if needed
	Ground	None
System and component redundancy requirement (1/2, 1/3, etc):	RF	2 ground stations per region; one satellite per region; Some aircraft may have redundant avionics
	Ground	2 ground stations per region
Physical channel characteristics (LOS, OTH, etc.):	RF	Geosynchronous Satellite LOS, with ~ 1/3 earth footprint
Electromagnetic interference (EMI) / compatibility characteristics	RF	DO-160D
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Primarily Oceanic. Currently InMarSat is not allowed to operate in domestic airspace.
Channel data rate (digital) and/or occupied band width (analog) requirement:		Voice: 10.5 Kbps/with 0.5 Forward Error Correction; Data: Aero-H: 9.6 Kbps; Aero-I: 4.8 Kbps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	Highly robust
System integrity (probability)	System	BER of 10^{-3} for voice, 10^{-5} for data

CHARACTERISTIC	SEGMENT	DESCRIPTION
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Voice is toll quality. Call blocking probability less than 1 per 50 attempts in busy hour
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight	RF	1/3 Earth Regional: Indian Ocean, Pacific Ocean, East Atlantic and West Atlantic regions overlap and cover the entire earth within +/- 85 degrees latitude.
Link and channel availability	RF	98.8% (spot beam) Satellite operates within the 10 MHz band assigned to AMS (R) S for satellite service by ICAO.
Security/ encryption capability	RF	N/A
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Commercial aircraft approximately 1,000 equipped out of estimated 2,000 oceanic fleet.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Aeronautical-Quadrature Phase Shift Key (A-QPSK), Aeronautical variation of QPSK
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	P-Channel (Packet): Time Division Multiplexing (TDM) for signaling and user data (ground-to-air) R-Channel(Random): Slotted Aloha, aircraft-to-ground signaling T-Channel (Reservation): TDMA - used for reserving time slots C-Channel (Circuit-mode): Used for voice
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	8 seconds/95% for 380 octet user packet at 10.5 kbps 45 seconds/95% for 380 octet user packet at 600 bps
	System	End to end delay within acceptable limits for voice transmission
Avionics versatility (applicability to other aircraft platforms)		Size and weight of Avionics and antenna are prohibitive for small aircraft.
Equipage requirements (mandatory for IFR, optional, primary, backup)	Avionics	Optional
	Ground	Ground Earth Stations (GES) required for receipt of satellite signals
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Proprietary hardware and software
	Avionics	Independent data link
Source documents		Inmarsat SDM; Nera System Summary; Inmarsat fact sheets; Annex 10, Aeronautical Telecommunications, International Civil Aviation Association (ICAO); ARINC Market Survey for Aeronautical Data Link Services; INMARSAT Aeronautical System Definition Manual

Although it is technically feasible to use "Voice over IP" (or voice over CLNP in the case of the ATN), we know of no such standards to have been considered for aeronautical use. The protocols are specified by ITU Recommendation H.323, "Packet Based Multimedia Communication Systems." If packet mode voice were used instead of circuit mode, it would be necessary to amend the FAR and corresponding ICAO requirements that two-way communication be maintained continuously.

5.4 Data Communication Using the ATN

The recommended architecture assumes that all two-way data communication is conducted using ATN compliant subnetworks. It is important to note that the Aeronautical Telecommunication Network is not a single network managed by one organization, but is similar to the Internet in that it uses a set of requirements to enable end-to-end communications over a collection of separate but interconnected networks.

All ATN implementations must comply with Chapter 3 of Annex 10, Volume III, Part1 and the related “Manual of Technical Provisions for the Aeronautical Telecommunication Network (ATN),” ICAO DOC 9705/AN956, or subsequent revisions.

The ATN architecture makes it possible to use a broad variety of subnetworks, with interfaces already specified for VDL Modes 2 and 3. In addition, the Technical Manual specifies mappings of the ATN priority levels to the priority levels defined for, inter alia, VDL and Mode-S. Satellite service providers can support the ATN through the use of a subnetwork dependent convergence facility (SNDCF) using ISO/IEC 8208:1995: “Information Technology—Data Communications—X.25 Packet Layer Protocol for Data Terminal Equipment.” Because other protocols may be more suitable for use with satellites, the ATN Panel has begun work on SNDCF for other protocols.

Arguably, it would be beneficial for the AATT 2015 architecture to have an SNDCF for the internet protocol (IP). Besides producing benefits of greater availability of implementations and likelihood of commercial investment in improving the protocols, research has begun on improvements for TCP/IP when using satellite communications. Existing protocols, including the OSI protocols on which ATN is based, do not fully address the satellite environment, which includes greater propagation delays, more noise, asymmetric channels for some implementations, and other characteristics.

Because of the limited demand for OSI, there is minimal likelihood of major technological advances in OSI protocols. ISO/IEC Joint Technical Committee 1 disbanded the committees working on OSI, with some projects cancelled and other project transferred to different subcommittees. The ITU continued to support the projects that had been collaborative with JTC1. We expect that there will be convergence between ATN and TCP/IP protocols, with future versions of ATN migrating to TCP/IP and enhancements to TCP/IP to support mobile routing, quality of service and other capabilities at the levels of performance and integrity needed for aeronautical route service communications.

The use of ATN routers makes it possible to use satellite or terrestrial links without the application being concerned about the link, as long as the link satisfies the requirements for Quality of Service (QoS) and policy based routing. This openness gives users the flexibility to decide on which communication equipment and services to use.

5.4.1 VDL Mode 2

VDL Mode 2 is a 1990s concept for aeronautical data link. It has been designed by the international aviation community as a replacement for ACARS. Many of the limitations of ACARS have been overcome in the VDL Mode 2 system. The best known improvement is the increase in channel data rate from the ACARS 2.4 kbps rate to a 31.5 kbps rate. The improved rate is expected to increase user data rates 10 to 15 times over the current ACARS. The variation is dependent upon user message sizes, channel loading assumptions, and service provider options. VDL Mode 2 can carry all message types carried by ACARS plus Air Traffic Service messages such as CPDLC which require performance levels of latency and message assurance not possible with ACARS.

VDL Mode 2 is a subnetwork in the Aeronautical Telecommunication Network, ATN, concept. ATN has been developed by ICAO to provide a global air/ground and ground/ground network for all aviation related traffic. ATN addresses both the communications aspects and the applications.

Table 5.4-1. VDL Mode 2 Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**VHF Digital Link Mode 2** (VDL Mode 2)
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	Very High Frequency (VHF)
	Ground	ARINC Data Network System (ADNS) & ARINC Packet Network (APN)
Frequency/ Spectrum of Operations		136.975MHz, 136.950MHz, 136.925MHz, 136.900MHz currently approved for VDL in international frequency plans. The 136.500 - 137.0 MHz band (20 channels) is potentially assignable to VDL Mode 2 in the U.S. Additional frequencies are based on availability and sharing critieria.
System Bandwidth Requirement	RF	25KHz
	Ground	Primary 56 Kbps , dial backup 64 Kbps ISDN
System and Channel Capacity (number of channels and channel size)	RF	Unlimited system growth - primarily dependent on regulatory frequency allocation. Ground stations are capable of four independent frequencies. Initial deployment will be based on aircraft equipage and will only require 1-2 frequencies.
	Ground	APN X.25 packet switched services and IP and ATN protocols
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Simplex - Transmission or reception on a single frequency but not simultaneously.
	Ground	Simplex
Method of information delivery (voice, voice recording, data, combination, etc.)	Avionics	data
	Ground	data
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	None
	Ground	The VDL Mode 2 ground network can prioritize messages over the wide area network and within the ground station in accordance with ATN priority schemes. Once presented to the radio for transmission, messages are not preempted.
Physical channel characteristics (LOS, OTH, etc.)		
	RF	Line Of Sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics	RF	RTCA DO-160C, Sections 15, 18, 19, 20, and 21.
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	First VDL Mode 2 usage expected in 2000 in En Route. Potentially applicable to all domestic phases of flight: Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight
Channel data rate (digital) and/or occupied band width (analog) requirement	RF	31.5 kbps/25KHz channel
Robustness of channel and system (resistance to interference, fading, multipath, atmospheric attenuation, weather, etc.)	RF	VHF channels are susceptible to terrain multipath but relatively robust and inherently resistant to fading, atmospheric attenuation, and weather.
System integrity (probability)	System	Design availability for Initial Operating Capability (IOC) is .9999. Higher availability will be achieved with additional ground stations and supporting network components for critical airports and applications.
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Within the VDL Mode 2 subnetwork, the probability of a lost packet is less than 10^{-7}. The subnetwork uses logical acknowledgements for packet delivery assurance. An additional end-to-end message assurance is applied to assure message delivery (all packets for a message).

CHARACTERISTIC	SEGMENT	DESCRIPTION
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Range dependent on altitude: Maximum 200 nm at 30,000 feet 80 nm at 5,000 feet Coverage: Implementation will begin in 2000 with U.S. En Route and high density airports (Airspace A and B). Coverage will expand as users equip.
Link and channel availability	RF	The availability of each ground station is 0.997. Ground station availability based on providing RF signal so radio and all components included. For typical applications, two ground stations will be available to achieve 0.9999 system availability.
Security/ encryption capability	RF	None at the RF level - VDL Mode 2 will support authentication and encryption of applications as planned by ATN.
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	None - system to be deployed in 2000. VDL Mode 2 is applicable to all user classes but is expected to be first implemented by air carriers and regional airlines operating in Class A airspace (above 18,000 feet) and associated Class B airspace airports.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Differential 8 Phase Shift Keying (D8PSK)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Carrier Sense Multiple Access (CSMA)
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	95% of messages delivered within 3.5 seconds within the VDL Mode 2 subnetwork. End-to-end delivery is estimated at 95% within 5 seconds.
Avionics versatility (applicability to other aircraft platforms)	System	VDL Mode 2 can be used for all applications.
	Avionics	VDL Mode 2 can be used on any class aircraft.
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.)	Ground	Ground stations must be installed for coverage
Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)	System	Signal in space characteristics are set by National and International standards. Avionics are developed by vendors with proprietary designs. Can share VHF equipment with other applications (VHF voice). The digital radios used by VDL Mode 2 are capable of providing analog voice service and/or VDL Mode 3 service with appropriate software and hardware additions. Radio is dedicated to one Mode when installed.
Source documents		ARINC VDL Mode 2/ATN Briefing for FAA

5.4.2 VDL Mode 3

VDL Mode 3 also is an ATN subnetwork. VDL Mode 3 has been designed for Air Traffic controller-pilot communications for both voice and data. VDL Mode 3 uses time division to split each 25 kHz channel into four subchannels, which can be any combination of voice or data. This approach allows VDL Mode 3 to provide a traditional voice service and a data link service over a single system. Each subchannel operates at 4.8 kbps. For voice service, VDL Mode 3 includes a voice encoder/decoder (vocoder) that allows digital signals to be converted to voice. As a data channel, VDL Mode 3 can provide data service at 4.8 kbps in each data subchannel.

VDL Mode 3 is under development by the FAA as part of the NEXCOM program. Initially, NEXCOM will provide digital radios to replace the current 25 kHz analog radios and will continue to operate in the double side-band amplitude modulated (DSB-AM) voice service mode.

Beginning in 2010, the digital radios will be reprogrammed to support the implementation of VDL-3. The technical characteristics of VDL Mode 3 are described in Table 5.3-1 above.

5.4.3 Inmarsat-3

Currently limited aviation communications is available via satellite. The Inmarsat GEO satellite provides voice and low-speed data service to aircraft in the Oceanic domain. The data service has been used to supplement HF voice air traffic control. Satellite voice for air traffic has been limited to emergency voice. The satellite services are installed on aircraft for commercial passenger voice service and the air traffic control services are provided as a secondary consideration. In an emergency, the pilot has priority access to the communication channel. The large dish size used for GEO satellites is expensive and difficult to install on smaller aircraft such as GA. Cargo aircraft do not have the passenger voice communications support, and therefore, traditionally have not been equipped with satellite communications equipment.

The technical characteristics of Inmarsat-3 are described in Table 5.3-2 above.

5.4.4 Inmarsat-4

The Inmarsat-4 (Horizons) satellites are proposed for 2001. Due to the crowded spectrum in L-band, Horizons may be deployed at S-band. Data rates of 144 kbps with an Aero-I aircraft terminal and 384 kbps with an Aero-H terminal are forecast. The Horizons satellites may have 150-200 spot beams and 15-20 wide area beams.

Table 5.4-2. Technical Characterization of Inmarsat 4—Horizons

Characteristic	Segment	Description
System Name:		**Inmarsat 4 - Horizons**
Communications/link type (HF, VHF, L-Band, SATCOM, other):Ground	RF	SATCOM - GEO. Four satellites
	Ground	Ground Earth Stations
Frequency/ Spectrum of Operations:	RF	S Band under consideration, L-Band dependent on world allocation
System Bandwidth Requirement:	RF	18 Mhz estimated
	Ground	Unknown
System and Channel Capacity (number of channels and channel size):	RF	Estimated 1,000 circuits/satellite using 15-20 beams
	Ground	
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Duplex
	Ground	
Method of information delivery (voice, voice recording, data, combination, etc.):	RF	Data
	Ground	Data
Data/message priority capability / designation (high, intermediate, low, etc.):	RF	Unknown
	Ground	Unknown
System and component redundancy requirement (1/2, 1/3, etc):	RF	Unknown
	Ground	Unknown
Physical channel characteristics (LOS, OTH, etc.):	RF	Geosynchronous satellite, LOS
Electromagnetic interference (EMI) / compatibility characteristics:	RF	Some S Band interference possible from existing ground station sources

Characteristic	Segment	Description
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	Ground	Primarily Oceanic. Currently InMarSat is not allowed to operate in domestic airspace.
Channel data rate (digital) and/or occupied bandwidth (analog) requirement:	RF	144 kbps and 384 kbps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	Relatively robust. Terrain multipath
System integrity (probability)	System	Unknown, should be equal or greater than INMARSAT 3
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Unknown, should be equal or greater than INMARSAT 3
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight	System	Geo-stationary worldwide
Link and channel availability	System	Unknown
Security/ encryption capability	System	Unknown
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Future system
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	System	Unknown
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	System	Unknown
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	System	Unknown
Avionics versatility (applicability to other aircraft platforms)	System	Probable size and weight of avionics indicate that it will be difficult to equip small aircraft
Equipage requirements (mandatory for IFR, optional, primary, backup)	System	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Will require ICAO SARPs
Source documents		ARINC Market Survey for Aeronautical Data Link Services

5.4.5 Other GEO Satellite Systems

Other GEO satellites have been proposed that potentially are applicable to the aviation market. They are described further in the Task 9 report. They include the AMSC/TMI satellites, Loral Skynet, CyberStar and Orion satellites, the ASC and AceS systems, and the proposed Celestri combination GEO/LEO satellite system. They are not discussed further in this report due to their limited service offering or due to their limited remaining satellite life expectancy. Many details of proposed satellites are unavailable either because they are proprietary developments or the designs still are in development. A representative 2007 GEO system based on the LM/TRW Astrolink and Hughes Spaceway systems is presented below.

Table 5.4-3. GEO Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		LM/TRW Astrolink GEO, Hughes Spaceway GEO. (At least one of these or a similar system should be operational in 2007)
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	Ka-band
	Ground	Unknown
Frequency/ Spectrum of Operations:	RF	Ka-band, 20 GHz downlink from satellite, 30 GHz uplink to satellite
System Bandwidth Requirement:	RF	500 MHz or more, each direction, maybe split 4 or 7 ways for frequency reuse in each cell (spot beam)
	Ground	
System and Channel Capacity (number of channels and channel size):	RF	16kbps to 2Mbps standard channels, hundreds of channels available. Over 100Mbps gateway or hub channels.
	Ground	Unknown
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	duplex, may be asymmetric
	Ground	Duplex
Method of information delivery (voice, voice recording, data, combination, etc.):	Avionics	Data
	Ground	Data
Data/message priority capability / designation (high, intermediate, low, etc.):	RF	Multiple priorities available
	Ground	Unknown
System and component redundancy requirement (1/2, 1/3, etc):	RF	Design life of 10 to 15 years, high system availability (0.9999 goal)
	Ground	Unknown, typically multiple ground stations in view
Physical channel characteristics (LOS, OTH, etc.):	RF	LOS
Electromagnetic interference (EMI) / compatibility characteristics:	RF	possible interference from terrestrial Ka-band systems (LMDS, fiber alternatives systems), regulated through spectrum licensing
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	All
Channel data rate (digital) and/or occupied band width (analog) requirement:		FDM/TDMA burst (packet) channels, variable bit rates, 1 to 100+ Mbps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	variable rate coding and variable data rates to mitigate deep rain fades, many frequencies available to avoid fixed interference
System integrity (probability)	System	0.9999 availability typical goal

CHARACTERISTIC	SEGMENT	DESCRIPTION
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	10^{-9} or better typical
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight	RF	global possible, but most systems do not intend to cover oceans and polar regions, GEO systems point spot beams to land masses and high population areas in particular
Link and channel availability	RF	0.9999 availability typical goal
Security/ encryption capability	RF	terminal authentication during access encryption can be overlaid, but not a basic feature
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Fixed ground terminal service beginning in 2003
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	digital, QPSK, burst (packets), FEC variable rates 1/2 or higher
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	FDM/TDMA
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	latency: approx. 0.3 second for GEO
	System	
Avionics versatility (applicability to other aircraft platforms)		Not designed for fast moving terminals, can be achieved if business is identified and the developer designs capability.
Equipage requirements (mandatory for IFR, optional, primary, backup)	Avionics	optional
	Ground	
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Proprietary
	Avionics	Independent
Source documents		FCC and ITU spectrum license applications, conference publications

5.4.5.1 ICO Global

MEO satellite systems have been proposed for the Aeronautical Mobile Service. MEO systems have several advantages over the GEO and LEO approaches. The reduced transmission distance of MEO systems provides a higher link margin. Compared to LEO systems, the MEO satellites are in view to an individual aircraft longer and experience less frequent handoffs. Boeing, ICO-Global, Celestri, and Teledesic are possible MEO satellites for the 2007 time frame. The following table is based on the ICO-Global system.

Table 5.4-4. ICO Global Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**ICO Global**
Communications/link type (HF, VHF, L-Band, SATCOM, other):		SATCOM MEO satellites; 10 satellites in two planes of 5 each (plus 2 spares)
Frequency/ Spectrum of Operations:	Service Band, Uplink	2.170 – 2.200 GHz
	Service Band, Downlink	1.98 – 2.010 GHz
	Feeder Band, Uplink	6.725 – 7.025 GHz
	Feeder Band, Downlink	5 GHz (AMS(R)S)
	Crosslink Band	N/A
System Bandwidth Requirement:	System	Unknown
System and Channel Capacity (number of channels and channel size):	RF	24,000 circuits total/4.8 Kbps voice
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Duplex
Method of information delivery (voice, voice recording, data, combination, etc.):	RF	GSM Voice
Data/message priority capability / designation (high, intermediate, low, etc.):	System	None
System and component redundancy requirement (1/2, 1/3, etc):	RF	10 satellites in two planes of 5 each (plus 2 spares)
Physical channel characteristics (LOS, OTH, etc.):	RF	LOS
Electromagnetic interference (EMI) / compatibility characteristics:	RF	Service Link Margin 8.5 dB, DO-160D for avionics
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	Ground	All
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	4.8 Kbps voice
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	Moderate. Max one-satellite duration: 120 minutes Connectivity characteristics: Simultaneous fixed view required
System integrity (probability)	System	Not stated
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Unknown
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight	System	Full earth coverage
Link and channel availability	RF	Not stated

CHARACTERISTIC	SEGMENT	DESCRIPTION
Security/ encryption capability	System	Not stated
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	RF	None
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	QPSK
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	TDMA (implied that path diversity and combining will be used
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Latency: ~140ms path + sat switching + 100ms in 2 codecs
Avionics versatility (applicability to other aircraft platforms)	RF	No avionics available.
Equipage requirements (mandatory for IFR, optional, primary, backup)	RF	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Proprietary
Source documents		ARINC Satellite Study

5.4.5.2 Iridium

The Iridium service is the only service other than Inmarsat that became operational and announced plans for an AMS(R)S service; the Iridium service now has been terminated. The Iridium system is shown in the following template to represent potential LEO systems, although Iridium has gone bankrupt and will not be available. The 66 satellite Iridium LEO system was designed for mobile voice and low-speed data and has been proposed for aeronautical mobile users. FCC filings had indicated future Iridium versions would provide higher speed data services. In addition to the low data rate, LEO systems must overcome the frequent handoff problem that occurs as a satellite transits the user location.

**Table 5.4-5.	Iridium Satellite Characteristics**

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name		**Iridium**
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	SATCOM; LEO satellites; 66 satellites in 6 planes of 11 each (plus 12 spares)

CHARACTERISTIC	SEGMENT	DESCRIPTION
Frequency/ Spectrum of Operations	Service Band, Uplink	1.62135 – 1.62650 GHz (AMS(R)S)
	Service Band, Downlink	1.62135 – 1.62650 GHz (AMS(R)S)
	Feeder Band, Uplink	29 GHz
	Feeder Band, Downlink	19 GHz
	Crosslink Band	23 GHz
System Bandwidth Requirement	System	10.5 MHz
	Channel	31.5 kHz/50 kbps/12 users
System and Channel Capacity (number of channels and channel size)	RF	3840 circuits/sat; 56,000 circuits total
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	System	duplex
Method of information delivery (voice, voice recording, data, combination, etc.)	System	Voice and data
Data/message priority capability / designation (high, intermediate, low, etc.)	System	None
System and component redundancy requirement (1/2, 1/3, etc)	RF	66 satellites in 6 planes of 11 each (plus 12 spares)
	Ground	Satellite-satellite switching for high ground system availability
Physical channel characteristics (LOS, OTH, etc.)	RF	LOS
Electromagnetic interference (EMI) / compatibility characteristics	RF	Service link margin: 16.5 dB no combining min BER 10^{-2} DO 1600 for avionics
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	Ground	All
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	2.4 Kbps and 4.8 Kbps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	High. Max one-satellite duration: 9 minutes Connectivity characteristics: Flex to any station at any location
System integrity (probability)	RF	$1x10^{-6}$
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Compressed voice, toll quality
Range/ Coverage/ footprint (oceanic, global, regional / line-of-sight	System	Full earth coverage
Link and channel availability	RF	99.5%
Security/ encryption capability	System	Proprietary protocol

CHARACTERISTIC	SEGMENT	DESCRIPTION
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	RF	No aviation usage
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	QPSK, FEC rate _,
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	FDMA/TDMA
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	12 ms path; 175 ms total
Avionics versatility (applicability to other aircraft platforms)	RF	No avionics available
Equipage requirements (mandatory for IFR, optional, primary, backup)	Avionics	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Proprietary
Source documents		ARINC Satellite Study

5.4.6 ORBCOMM

Although the Orbcomm service does not operate in an AMS(R) band, it is used for provision of routine weather products to aircraft; the system is described below.

Table 5.4-6. Technical Characterization of Orbcomm

Characteristic	Segment	Description
System Name:		**ORBCOMM**
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	SATCOM – LEO satellites. 35 satellites currently, an additional launch is planned for 2000 (enhancing coverage in the equatorial regions of the world).
	Ground	Ground Earth Station
Frequency/ Spectrum of Operations:	Downlinks	137 –138 MHz and 400 MHz
	Uplinks	148 – 150 MHz
System Bandwidth Requirement:	RF	50 kHz
	Ground	N/A

Characteristic	Segment	Description
System and Channel Capacity (number of channels and channel size):	RF	Unknown
	Ground	N/A
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Simplex
	Ground	Unknown
Method of information delivery (voice, voice recording, data, combination, etc.):	Avionics	Data
	Ground	Data
Data/message priority capability / designation (high, intermediate, low, etc.):	RF	None
	Ground	None
System and component redundancy requirement (1/2, 1/3, etc):	RF	GES redundancy. Satellites are overlapping in coverage.
	Ground	GES is redundant and has two steerable high-gain VHF antennas that track satellites.
Physical channel characteristics (LOS, OTH, etc.):	RF	Low Earth Orbit (LEO) satellites. LOS
Electromagnetic interference (EMI) / compatibility characteristics:	RF	N/A
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	Ground	All
Channel data rate (digital) and/or occupied bandwidth (analog) requirement:	RF	2400 bps uplink; 4800 bps downlink; 9600 bps downlink (future)
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	Not stated
System integrity (probability)	System	Not stated
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Store and forward message assurance
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight	RF	Worldwide coverage
Link and channel availability	RF	Not stated
Security/ encryption capability	RF	Not stated
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	No avionics available.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Not stated
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Not stated
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Unknown
	System	Unknown
Avionics versatility (applicability to other aircraft platforms)	Avionics	Avidyne markets the Echo Flight system, which uses Orbcomm for delivery of weather products on a request-reply basis.

Characteristic	Segment	Description
Equipage requirements (mandatory for IFR, optional, primary, backup)	Avionics	Not approved
	Ground	GES required for receipt of satellite signals
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Proprietary
	Avionics	N/A
Source documents		www.orbcomm.com

5.4.7 HFDL (GLOBALink/HF)

HF data link provides an alternative to oceanic satellite data and HF voice communications. The aircraft changes are small, consisting primarily of a radio upgrade and a new message display capability. HF antenna and aircraft wiring can remain the same. HFDL is cheaper to install and operate than satellite. For cargo aircraft that do not need the passenger voice service of satellite, HFDL provides a cost effective data link. HFDL is adaptive to radio propagation and interference. It seeks the ground station with the best signal and adjusts the data signaling rate to reduce errors caused by interference. HFDL service is faster, less error prone, and more available than traditional HF voice communications. HFDL has not yet been approved for carrying air traffic messages and aircraft equipage is just beginning.

Table 5.4-7. HFDL Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		HIGH FREQUENCY DATA LINK (HFDL) (GLOBAlink/HF)
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	High Frequency (HF)
	Ground	ARINC Data Network System (ADNS) & ARINC Packet Network (APN)
Frequency/ Spectrum of Operations:		2.8 MHz to 22 MHz
System Bandwidth Requirement:	RF	3 kHz Single Side band, carrier frequency plus 1440 Hz. Each Station provides 2 channels
	Ground	N/A
System and Channel Capacity (number of channels and channel size):	RF	Two channels per ground station
	Ground	ADNS & APN X.25 packet switched services
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Half-duplex
	Ground	Full duplex with a separate channel for each transmit and receive path, however the communications equipment often blocks receive voice when the operator is transmitting resulting in a half-duplex operation.
Method of information delivery (voice, voice recording, data, combination, etc.):	Avionics	Data
	Ground	Data

CHARACTERISTIC	SEGMENT	DESCRIPTION
Data/message priority capability / designation (high, intermediate, low, etc.):	RF	N/A
	Ground	A ground based priority and preemption capability that enables Air Traffic Services (ATS) messages to be delivered ahead of Aeronautical Operational Control (AOC) messages. A higher priority single or multiblock ATS message will be serviced before lower priority multiblock messages. The transmission of lower priority multiblock messages will resume when the higher priority message is completed. Lower priority messages will be delivered in their entirety to the aircraft. Lower priority single-block messages are not preempted due to protocol and avionics implementation requirements. The immediate preemption by higher priority messages of lower priority multiblock messages is also supported.
System and Component Redundancy	RF	HFDL Ground Stations (HGS) are geographically located to provide a 1 / 2 equipment diversification with each site transmitting two frequencies to provide a 1 / 4 relationship for radio frequencies.
	Ground	ETE availability for HFDL through ADNS and APN provides redundancy with an availability of 1.00000. In the North Atlantic Region redundancy is also provided with an equipment availability of.99451 for the passport backbone Access Module. In the Pacific Region total redundancy is provided ETE.
Physical channel characteristics (LOS, OTH, etc.):	RF	Via ionosphere
Electromagnetic interference (EMI) / compatibility characteristics:	RF	DO-160D
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	Adaptable to propagation conditions: 1800, 1200, 600, 300 bps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	Signals in the HF band are influenced by the characteristics inherent in transmitting through the ionosphere, which include various emissions from the sun interacting with the earth's magnetic field, ionosphere changes, and the 11-year sunspot cycle which affects frequency propagation. HF is also affected by other unpredictable solar events. Frequency management techniques are used to mitigate these effects
System integrity (probability)	System	No integrity requirement for 2007 data services, Forward error detection
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	95% of uplink message blocks in 60 seconds (one-way); 95% of uplink message blocks in 75 seconds (round-trip); 99% of uplink message blocks in 180 seconds (round-trip
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	3,000 nm from each ground station. Ten stations deployed as of December 1999 with 3-4 more sites under consideration to complete Global coverage.
Link and channel availability	RF	≥99.8% End to End Operational Availability
Security/ encryption capability	RF	None
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Commercial aircraft, 50-100 equipped. New service with potential 8,000 users

CHARACTERISTIC	SEGMENT	DESCRIPTION
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	M-Phase Shift Keying (M-PSK) 1800 (8-PSK); 1200(4-PSK); 600 (2-PSK); 300 (2-PSK)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.) Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Slotted TDMA
Timeliness/latency delay requirements	RF	Uplink end-to-end: 2 minutes/95%, 6 minutes/99% of messages Downlinks end-to-end: 1 minute/95%, 3 minutes/99%
Avionics versatility (applicability to other aircraft platforms)	Avionics	Any aircraft equipped with HF transmit and receive equipment and the appropriate HFDL interface unit
Equipage requirements (mandatory for IFR, optional, primary, backup, etc.)	Avionics	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications, etc.)	System	Signal in space defined by national and international standards. HF Voice equipment may be shared with other HF applications (i.e., HF voice).
Source documents		Annex 10, AERONAUTICAL TELECOMMUNICATIONS, ICAO; ARINC Quality Management Reports, Air/Ground Voice Performance; ARINC specification 635-2 ARINC Aeronautical Data Link Proposal, 1997; HFDL Ground Station System Segment Specification

5.4.8 Effects of Modulation Schemes on Performance

The ICAO AMCP and RTCA Special Committee 172 for data link considered a number of modulation schemes. The ones considered in detail were Differential Eight-Phase Shift Keying (D8PSK), Eight-Level Frequency Modulation (8LFM), 4-ary Quadrature Amplitude Modulation (4QAM), and 16-ary QAM (16QAM). Key considerations were a desire to achieve the maximum bit rate within the existing 25 kHz channel spacing.

The resulting report showed that Working Group C examined four detailed proposals for the VDL Mode 2 modulation scheme (namely 4QAM, 16QAM, 8LFM, and D8PSK) after having been provided background information on these and many other digital modulations. Based on analysis, simulation and direct measurement, the following conclusions are presented:

4QAM has insufficient throughput and is eliminated from consideration as a primary modulation. It initially was to be the backup mode for 16QAM where a link could not be established because of range or fading.

16QAM is the most complex scheme and is significantly more costly than the others. It has a less certain performance at longer ranges and under fading conditions.

8LFM with a nonlinear transmitter that can provide more RF power on the channel provides more margin than D8PSK. D8PSK has greatly superior ACI performance for digital modulation against digital modulation however.

D8PSK has been found to be the most efficient digital modulation scheme that can be implemented with currently available technology while meeting the spectral limitations of a 25 kHz channel.

D8PSK provides a channel data rate of 31.5 kilo bits per second with a baud rate of 10.5 k baud and three bits per symbol.

The analysis indicated that 16QAM could yield a throughput of 37.8 kb/s for longer (1024 octet) messages. Potentially, weather services would use longer message sizes and could benefit from the greater throughput. The Adjacent Channel Interference (ACI) would be a significant factor however, if a weather service is proposed in the aeronautical VHF band. An additional consideration will be the expected availability of radios and experience with D8PSK due to their use for VDL Mode 2 and Mode 3.

5.4.9 ACARS Transition

Although ACARS currently is used for data communication, the existing ACARS networks are being transitioned to VDL-2. ARINC's GLOBALink™ service is designed to be used as an ATN compliant subnetwork, but it includes provisions for supporting legacy ACARS applications. Nevertheless, because of the superior performance of VDL-2 with respect to the Mode A network, and the more stringent performance requirements of ATM communications vis-à-vis AOC, the legacy ACARS network is not considered part of the recommended AATT architecture for 2015.

5.5 Ground-to-Air Broadcast Communication Using Non-ATN Protocols

Ground-to-air broadcast services will not be used for safety, distress, or urgency communication, so they are not subject to the same stringent requirements as ATM communications. Since the intention of the architecture is to leverage available capacity on commercial satellites, the service provider is likely to determine the specifications for the protocols, although these often will be based on ITU recommendations or TCP/IP standards in preference to proprietary protocols.

Suitability of the service providers' protocols may need to be determined on a case-by-case basis. The ICAO AMCP has formalized a set of acceptability criteria for evaluating potential providers of Next Generation Satellite Services (NGSS). We recommend that acceptability criteria be developed for broadcast systems. In addition, it would be useful to develop upper layer protocols for interfacing to broadcast service providers so that a broadcast application would need to support only one interface regardless of the service provider.

5.5.1 VHF Digital Link—Broadcast (VDL-B)

VDL-B is a broadcast variation of VDL Mode 2. Currently intended for Flight Information Services, VDL-B provides weather information to suitably equipped aircraft. The broadcast approach can increase the throughput of data to the user since the protocol overhead of request/reply and confirmation are not required. Under the FIS Policy, two VHF band frequencies were provided to each of two vendors for implementation. As a condition of the frequency, each vendor is required to transmit a minimum set of weather products. The vendor is allowed to charge fees for additional optional products such as weather graphics. The protocols for the FIS-B systems are partially proprietary and may be specified by the vendor. The vendors are expected to use the D8PSK physical layer, but the upper layers are not standardized.

VDL-B is not an ICAO SARPs-recognized version of VDL. The VDL-B term has been used to describe a data link intended primarily or solely for broadcast of data one-way to aircraft. Weather and traffic information frequently are recommended applications for broadcast functions. The description in this report is based on VDL Mode 2 and FIS, which is the most common usage of the term VDL-B. Other variations of VDL-B are possible since it is not an official term or definition.

Table 5.5-1. VDL Broadcast Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name		**VHF Data Link—Broadcast (VDL-B)**
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	Very High Frequency (VHF)
	Ground	Leased telco for current implementation. VDL Mode 2 network possible in the future. Other proprietary solutions possible.
Frequency/ Spectrum of Operations		118-137MHz
System Bandwidth Requirement	RF	25KHz
	Ground	N/A
System and Channel Capacity (number of channels and channel size)	RF	Two frequencies per vendor, Total of four frequencies.
	Ground	Leased telco.
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Broadcast
	Ground	Duplex (return needed for ground station monitor and control)
Method of information delivery (voice, voice recording, data, combination, etc.)	Avionics	Data
	Ground	Data
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	None
	Ground	VDL-B is a proposed broadcast service that provides advisory and weather information to all aircraft monitoring the channel. The information provided contributes to the safety of flight. This service is similar to Flight information services (FIS)
System and component redundancy requirement (1/2, 1/3, etc)	RF	Since FIS is an advisory service, high availability is not required and redundancy will probably not be used.
	Ground	None expected.
Physical channel characteristics (LOS, OTH, etc.)	RF	Line of sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics	RF	DO-1600
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	The FIS-B information will be available in all phases of flight if the aircraft is within range of the ground station. En Route will have the most coverage while coverage on the ground will be limited. Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	31.5 KBPS if D8PSK used 19.2 for GMSK Other data rates possible
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	RF is robust and resistant to interference, fading, multi-path, atmospheric attenuation, weather
System integrity (probability)	System	Based on non-critical service category, availability is estimated as 0.99

CHARACTERISTIC	SEGMENT	DESCRIPTION
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Unknown
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	LOS (180 nautical miles for aircraft at 25,000 feet) 80 nm at 5,000 feet
Link and channel availability	RF	0.99
Security/ encryption capability	RF	None
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Intended for G/A market but available to all users.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Differential 8 Phase Shift Keying (D8PSK) or Gaussian Mean Shift Keying (GMSK)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Broadcast mode has not been defined
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Unkown
	System	> 5 seconds
	Avionics	Optional
	Ground	Required for message transmission
Avionics Versatility	Avionics	If D8PSK approach used, then the radio could be used for multiple applications.
Equipage Requirements	RF	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)	Ground	Required for message transmission
	System	Proprietary hardware/software mix.
	Avionics	Can share VHF equipment with other applications
Source documents		None

5.5.2 Satellite Digital Audio Radio Service (SDARS)

The Satellite Digital Audio Radio Service (SDARS) was established to provide continuous nationwide radio programming with compact disc quality sound. It is intended to be able to offer niche programming that will serve listeners with special interests. In addition, SDARS has the technological potential to provide a wide range of audio programming options to rural and mountainous sections of the country that historically have been under-served by terrestrial radio.

Two companies, American Mobile Radio Corporation and CD Radio (now Sirius Satellite Radio), were awarded frequency authorizations by the FCC.

Although the intended purpose of the system is to provide audio entertainment for automobiles and remote areas, the 64 kHz channels could serve as media for data broadcasts (including graphics) as well. Both companies have established agreements with automobile manufacturers to install radios, which indicates that there are manufacturers for the receivers and antennas. If this technology were used for transmission of weather maps, the market for these products could extend beyond aviation, as many operators of truck fleets might be interested in acquiring broadcast weather services or other broadcast capabilities.

Table 5.5-2. SDARS Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name		**Satellite Digital Audio Radio System (SDARS)**
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	Satellite Broadcast, S-band
Frequency/ Spectrum of Operations		Sirius Satellite Radio has the license for 2320-2332.5 MHz; AMRC has the license for 2332.5-2345 MHz
System Bandwidth Requirement	RF	12.5 MHz
System and Channel Capacity (number of channels and channel size)	RF	Sirius offers fifty 64 KHz channels
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Broadcast
Method of information delivery (voice, voice recording, data, combination, etc.)	Avionics	Digital Audio
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	Dedicated channels
System and component redundancy requirement (1/2, 1/3, etc)	RF	Two satellites
	Ground	Unknown
Physical channel characteristics (LOS, OTH, etc.)	RF	Line of sight
Electromagnetic interference (EMI) / compatibility characteristics	RF	Unknown
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Not intended for aeronautical applications
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	No published information
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	Unknown
System integrity (probability)	System	Unknown
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	High
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Regional - intended for U.S.

CHARACTERISTIC	SEGMENT	DESCRIPTION
Link and channel availability	RF	Unknown
Security/ encryption capability	RF	Unknown - probable proprietary signal to deter theft
Avionics	RF	N/A
Equipage Requirements	RF	None
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	N/A
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	XM
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Unknown
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Unknown
	System	Unknown
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)	System	Proprietary
Source documents		FCC and Sirius web sites

5.6 Air-Air and Air-Ground Broadcast Communications

5.6.1 Mode-S

Mode-S is an evolution of the traditional Secondary Surveillance Radar (SSR). For Mode-S, each aircraft has a unique 24-bit address, which allows transmission selectively addressed to a single aircraft instead of broadcast to all aircraft in an antenna beam. The Mode-S transponder has 56 bit registers that can be filled with airborne information such as aircraft speed, waypoint, meteorological information, and call sign. The information in the register can be sent either by an interrogation from the ground system or based on an event such as a turn. For ADS-B, equipped aircraft can exchange information without a master ground station. Although capable of sending weather and other information, the Mode-S communications capability is allocated to support its surveillance role and will consist of aircraft position and intent. ADS-B uses the Mode-S downlink frequency (i.e., 1090 MHz) and link protocols to squitter (i.e., spontaneously broadcast) onboard derived data characterizing the status (current and future) of own aircraft or surface vehicle via various ADS-B extended squitter message types (e.g., State Vector [position/velocity], Mode Status [identification/type category/current intent], and On-Condition [future intent/coordination data]).

Table 5.6-1. Mode-S Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name		**Mode S**
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	
	Ground	L-Band (also known as D-Band)
Frequency/ Spectrum of Operations:		1090 MHz, +/- 1MHz
System Bandwidth Requirement:	RF	2 MHz (based on the existing Mode-S downlink)
	Ground	Leased telecommunications
System and Channel Capacity (number of channels and channel size):	RF	Single 2 MHz channel
	Ground	Leased telecommunications
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Broadcast from aircraft
	Ground	Ground stations transmit at 1030 MHz and receive at 1090 MHz. For ADS-B service, receive only stations have been proposed.
Method of information delivery (voice, voice recording, data, combination, etc.):	Avionics	Data
	Ground	Data
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	Surveillance function has priority over communications function
	Ground	None. The probability of successful message reception and report update are specified (see Table 3-4 of RTCA DO-242 ADS-B MASPS) depending upon the specific operational applications being supported by the ADS-B system. In this broadcast system more critical data (as determine by the operation being supported) are broadcast more frequently to improve the probability of message reception and report update.
System and component redundancy requirement (1/2, 1/3, etc):	RF	This depends on the ADS-B equipage class, its hardware implementation, and the specific operational applications being supported. The system level minimum availability requirements for equipage classes A1 through A3, for example, is 0.999. This, coupled with the minimum system level continuity of service requirement for the probability of being unavailable during an operation of no more than 2×10^{-4} per hour of flight along with the specific availability requirements for the operation being performed (e.g., parallel approach), will determine whether equipment redundancy is needed to satisfy the operational requirement. This is expected to be part of the certification process and will be based on the intended use of the ADS-B equipment and the operational approval(s) being sought.
Physical channel characteristics (LOS, OTH, etc.):	RF	Line Of Sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics:	RF	ADS-B equipment has broad EMI requirements: transmitting and/or receiving equipment shall not compromise the operation of any co-located communication or navigation equipment (i.e., GPS, VOR, DME, ADF, LORAN) or ATCRBS and/or Mode-S transponders. Likewise, the ADS-B antenna shall be mounted such that it does not compromise the operation of any other proximate antenna.
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Operational applications supported by ADS-B have been identified across all phases of flight, except possibly pre- and post-flight.
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	1 Mbps Mode-S provides data link capability as a secondary service to surveillance. Extended length message, ELM, format provides 80 user bits per 112 bit message. A typical rate is one ELM per four seconds (RTCA DO-181)

CHARACTERISTIC	SEGMENT	DESCRIPTION
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	The L-Band frequency is subject to fading and multi-path; Mode-S uses a 24-bit parity field and forward error detection and correction (FEDC) to help address this.
System integrity (probability)	System	ADS-B integrity is defined in terms of the probability of an undetected error in an ADS-B report received by an application, given that correct source data has been supplied to the ADS-B system. ADS-B system integrity is 10^{-6} or better on a per report basis. [Note: Due to constraints imposed by the Mode-S extended squitter message length, multiple messages must typically be received before all required data elements needed to generate a particular ADS-B report are available.]
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Mode-S system performance for undetected error rate is specified to be less than one error in 10^{-7} based on 112-bit transmissions.
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Assuming LOS exists, range performance depends on traffic density and the 1090 MHz interference environment (i.e., ADS-B uses the same frequency as ATC transponder-based surveillance). In low-density environments (e.g., oceanic) range performance is typically 100+ nm, while in a high-traffic density and 1090 interference environments (e.g., LAX terminal area) the range performance is on the order of 50 to 60 nm with current receiver techniques (improved processing techniques have been identified that are expected to provide range performance to 90 nm in dense environments).
Link and channel availability	RF	100%, as ADS-B is a true broadcast system
Security/ encryption capability	RF	None
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	TBD, since still being developed. However, a significant number of initial implementations are expected to occur in aircraft already equipped with TCASII/Mode-S transponders (commercial air transport and high-end business aircraft). This area of equipage (i.e., TCASII/Mode-S) is expected to increase as the ICAO mandate for TCASII Change 7 (called ACAS in the international community) starts to occur in 2003.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Pulse Position Modulation (PPM) Each ADS-B message consists of a four pulse preamble (0.5 microsecond pulses, with the 2nd, 3rd, and 4th pulses spaced 1.0, 3.5, and 4.5 microseconds after the 1st) followed by a data block beginning 8 microseconds after 1st preamble pulse. The data block consists of 112 one-microsecond intervals with each interval corresponding to a bit (a binary "1" if a 0.5 pulse is in the first half of the interval or a "0" if the pulse is in the second half of the interval.
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Random access; squitter transmissions are randomly distributed about their mean value between some fixed high and low limits (e.g., "one-second" squitters have a one second mean value and are randomly transmitted every 0.8 to 1.2 seconds). This done to minimize collisions on the link. When collisions do occur, the receiver uses the next available message (which in a broadcast system like ADS-B will arrive shortly) to obtain the data.
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	
	ADS-B System	ADS-B uncompensated latency must be less than 1.2 ms or 0.4 ms depending upon the uncertainty of the position data (error [95% probable]) being used to support a particular operational application. The error is categorized according to navigation uncertainty categories (NUCs) from 1 to 9, with the higher NUCs indicating more accurate position data. The 1.2 ms requirement applies to NUCs less than 8 (0.05 to 10 nm position error), while the 0.4 ms must be met for NUCs 8 or 9 (3 to 10 m error).

CHARACTERISTIC	SEGMENT	DESCRIPTION
Avionics versatility (applicability to other aircraft platforms)	Avionics	ADS-B as defined is intended to be applicable to all aircraft category types as well as surface vehicles operating in the aircraft movement area of an airport. A range of equipage classes have been defined to accommodate the various levels of user requirements from GA to air transport.
Equipage requirements (mandatory for IFR, optional, primary, backup, etc.)	Avionics	No mandate of the ADS-B system is planned. However, if ADS-B equipment is used to perform a particular operation (e.g., IFR), a specific ADS-B equipage class, with certain minimum performance characteristics (e.g., transmitter power), will be required.
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)	Ground	No mandate of the ADS-B system is planned. However, if FAA were to use ADS-B to monitor ground vehicles on the airport movement areas, all such vehicles would have to be equipped with at least a minimum (i.e., broadcast-only) ADS-B system.
	System	ADS-B uses the Mode-S architecture which is a sub-network of the ATN and is based on an open system architecture.
	Avionics	The signal in space characteristics are defined by national and international forums.
Source documents		RTCA DO-242 ADS-B MASPS, RTCA DO-181 Mode-S MOPS, draft material for 1090 MHz ADS-B MOPS

5.6.2 Universal Access Transceiver (UAT)

The Universal Access Transceiver concept is intended for distribution of surveillance and weather data. It uses a unique hybrid access method of TDMA and random access. The TDMA portion is used to transmit the traffic and weather information while the random access portion is used by aircraft to transmit their own location in conformance with the RTCA DO-242 broadcast approach. The system is experimental and currently operates on a UHF frequency of 966 MHz. The bandwidth of the system is 3 MHz and a suitable frequency assignment would be difficult. UAT has not been standardized and is not currently recognized by ICAO/ATN. The system is being evaluated in the Safe Flight 21 initiative and would become an open system architecture if developed. The UAT implementation of ADS-B functionality had as its genesis a Mitre IR&D effort to evaluate a multi-purpose broadcast data link architecture in a flight environment. Its use for ADS-B was seen as a capacity and performance driver of the link. The current evaluation system (no standard exists or is in process at this time) uses a single frequency (experimental frequency assigned), a binary FM waveform, and broadcasts with 50 W of power. The system provides for broadcast burst transmissions from ground stations and aircraft using a hybrid TDMA/random access scheme. The UAT message structure, net access scheme, and signal structure have been designed to support the RTCA DO-242 ADS-B MASPS (i.e., to transmit State Vector, Mode Status, and On-Condition messages and provide the corresponding ADS-B reports for use by operational applications). The UAT is also investigating support for other situational awareness services (e.g., TIS-B & FIS-B) through sharing of the channel resources with ADS-B.

Table 5.6-2. UAT Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**UAT**
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	UHF
Frequency/ Spectrum of Operations	System	The UAT evaluation system operates on an experimental frequency assignment of 966 MHz. [Note: This band was selected due to the availability of spectrum. However, the system is not frequency specific and could operate in any suitable spectrum.]
System Bandwidth Requirement	RF	3 MHz
	Ground	≥ 1 MHz

CHARACTERISTIC	SEGMENT	DESCRIPTION
System and Channel Capacity (number of channels and channel size)	RF	One channel, 2 MHz
	Ground	Single 1 MB/s channel
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Two part: Ground broadcasts information to aircraft, aircraft transmit position information.
	Ground System	Telco
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	None
System and component redundancy requirement (1/2, 1/3, etc)	Ground	None, broadcast system. The probability of successful message reception/report update are specified (see Table 3-4 of RTCA DO-242 ADS-B MASPS) depending upon the specific operational applications being supported by the ADS-B system. The more critical data (as determine by the operation being supported) have minimum requirements that broadcast more frequently to improve the probability of message reception and report update. [Note: The ground station TDMA access protocol (see access scheme description below) may have some capability for message prioritization. However, this could not be determined from the documentation available.]
	RF	This is still to be determined. It depends on the ADS-B equipage class, its hardware implementation, and the specific operational applications being supported. The system level minimum availability requirements for equipage classes A1 through A3, for example, is 0.999. This, coupled with the minimum system level continuity of service requirement for the probability of being unavailable during an operation of no more than 2×10^{-4} per hour of flight, along with the specific availability requirements for the operation being performed (e.g., parallel approach), will determine whether equipment redundancy is needed to satisfy the operational requirement. This is expected to be part of the certification process and will be based on the intended use of the ADS-B equipment and the operational approval(s) being sought.
Physical channel characteristics (LOS, OTH, etc.)	RF	LOS
Electromagnetic interference (EMI) / compatibility characteristics	RF	UAT is being designed for operation on a clear channel. Interference to or from off-channel systems can only be assessed once an operational frequency is identified. DO-160D
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Primarily En Route but operational applications supported by ADS-B have been identified across all phases of flight, except possibly pre- and post-flight. UAT is being designed to support all ADS-B applications (as defined by DO-242)
Channel data rate (digital) and/or occupied band width (analog) requirement	RF	1 Mbps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	In general, the UHF frequency is subject to fading and multipath; UAT uses a 48-bit Reed-Solomon forward error correction (FEC) code and a 24-bit cyclic redundancy code (CRC) (acts as a 24-bit parity code) to help address this.

CHARACTERISTIC	SEGMENT	DESCRIPTION
System integrity (probability)	System	UAT will be judged according to ADS-B standards. ADS-B integrity is defined in terms of the probability of an undetected error in an ADS-B report received by an application, given that correct source data has been supplied to the ADS-B system. ADS-B system integrity is 10^{-6} or better on a per report basis. Currently, the UAT worst-case overall undetected error probability for an ADS-B message is 3.7×10^{-11}, which exceeds the minimum requirement. [Note: For UAT ADS-B messages map directly (i.e., one-to-one correspondence) to ADS-B reports (i.e., they are not segmented as they are in Mode-S ADS-B).]
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Worst-case overall undetected error probability for an UAT ADS-B message is 3.7×10^{-11}
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	LOS. Similar to VHF: 200 nm at 30,000 feet, 80 nm at 5,000 feet. The UAT proposal is to establish a series of ground stations to provide coverage over the U.S. at low (5,000 feet) altitude.
Link and channel availability	RF	Estimated at 0.99 since it will be an advisory service.
Security/ encryption capability	RF	None
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	None. This is a new system design that is not implemented. It currently has appeal and support from the GA community who perceive it to be a lower cost and possibly improved performance alternative to other ADS-B candidate systems (i.e., Mode-S and VDL Mode 4). However, frequency allocation, product development, and standardization/certification of a final design will have to occur before the validity of this perception can be determined.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	UAT uses both TDMA and Binary Continuous Phase Frequency Shift Keying in its signal cycle. The TDMA signal is used by the ground station for broadcast uplink. The Binary portion is used by aircraft to report position.
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	TDMA
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	UAT uses multiple access techniques: time division multiple access (TDMA) in the first portion (e.g., 188 ms) of a one second "frame" (i.e., slots to separate ground station messages from the aircraft and surface vehicle messages) and random access in the second portion (e.g., 812 ms) of the frame for ADS-B messages from aircraft and surface vehicles.
Avionics versatility (applicability to other aircraft platforms)	RF	UAT is being designed to meet ADS-B requirements. ADS-B uncompensated latency must be less than 1.2 ms or 0.4 ms depending upon the uncertainty of the position data (error [95% probable]) being used to support a particular operational application. The error is categorized according to navigation uncertainty categories (NUCs) from 1 to 9, with the higher NUCs indicating more accurate position data. The 1.2 ms requirement applies to NUCs less than 8 (i.e., 0.05 to 10 nm position error), while the 0.4 ms must be met for NUCs 8 or 9 (i.e., 3 to 10 nm error).
Equipage requirements (mandatory for IFR, optional, primary, backup, etc.)	RF	Optional

CHARACTERISTIC	SEGMENT	DESCRIPTION
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)	Avionics	UAT is a new system design being developed from scratch to meet ADS-B requirements. Therefore, since ADS-B as defined is intended to be applicable to all aircraft category types as well as surface vehicles operating in the aircraft movement area of an airport, UAT should be expected to have the avionics versatility needed to address the set of ADS-B requirements. A range of ADS-B equipage classes have been defined to accommodate the various levels of user requirements from GA to air transport
	Ground	Design information available to all vendors
	System	UAT is a new system and currently does have any standards (e.g., RTCA MOPS or ICAO SARPS).
Source documents	UAT	UAT system information was obtained from various briefings to RTCA SC-186 Plenary meetings and private Mitre correspondence. The system description is largely for an evaluation system involved in the current Safe Flight 21 tests and can be expected to change.

5.6.3 VDL Mode 4

VDL Mode 4 is a combined communication and surveillance concept. VDL Mode 4 also is termed Self-Organizing TDMA in reference to the ability of the system to mediate access to the time slots without reliance on a master ground station. With STDMA, the users can vary their channel access (number of time slots used) based on their need and the current loading of the channel. This technique makes VDL Mode 4 highly flexible and adaptable but less consistent in performance for critical functions. ICAO currently is validating the surveillance application for VDL Mode 4. Both Gaussian Filtered Frequency Shift Keying (GFSK) at 19.2 kbps and D8PSK at 31.5KBPS have been proposed for VDL Mode 4. Recently the D8PSK mode was removed from consideration based on superior performance by the GFSK method.

Table 5.6-3. VDL Mode 4 Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**Very High Frequency Digital Link Mode 4 (VDL Mode 4)**
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	VHF
	Ground	Undetermined
Frequency/ Spectrum of Operations:		118-137MHz
System Bandwidth Requirement:	RF	25KHz, Since all users need to exchange information on a common channel, VDL Mode 4 will use only one frequency/channel in an area.
	Ground	Undefined
System and Channel Capacity (number of channels and channel size):	RF	VDL Mode 4 is a developmental system. This information has not been defined.
	Ground	Undefined
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Simplex - Transmission or reception on a single frequency but not simultaneously. Channel is shared using TDMA.
	Ground	Half Duplex
Method of information delivery (voice, voice recording, data, combination, etc.):	Avionics	data
	Ground	data
Data/message priority capability / designation (high, intermediate, low, etc.):	RF	ATN subnetwork expected
	Ground	Undefined - none expected

CHARACTERISTIC	SEGMENT	DESCRIPTION
System and component redundancy requirement (1/2, 1/3, etc):	RF	none required, optional redundancy defined
	Ground	Unknown
Physical channel characteristics (LOS, OTH, etc.):	RF	Line Of Sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics:	RF	N/A
Channel data rate (digital) and/or occupied bandwidth (analog) requirement:	RF	19.2KBPS using Gaussian Filtered Frequency Shift Keying (GFSK); 31.5KBPS using D8PSK
Robustness of channel and system (resistance to interference, fading, multipath, atmospheric attenuation, weather, etc.)	RF	Will meet or exceed the requirements for VDL Mode 2 where RF is robust and resistant to interference, fading, multi-path, atmospheric attenuation, weather
System integrity (probability)	System	Undetermined (should be in range of 10^{-6})
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Undetermined
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Line Of Sight (180 nautical miles for aircraft at 25,000 feet) 80 nautical miles at 5,000 feet
Link and channel availability	RF	Undefined , due to surveillance requirement should meet 0.99999
Security/ encryption capability	RF	none
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Available to commercial, G/A, and military aircraft (will also be available aircraft to aircraft) Current users estimated as 100 GA.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	GFSK = 19.2 KBPS D8PSK = 31.5 KBPS
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Self-Organizing Time Division Multiple Access (S-TDMA)
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Will meet or exceed VDL Mode 2 (< 250 msec)
Avionics versatility (applicability to other aircraft platforms)	System	Will meet or exceed VDL Mode 2 (< 5 seconds)
	Avionics	N/A
Equipage Requirements	Avionics	Optional

CHARACTERISTIC	SEGMENT	DESCRIPTION
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)	Ground	Mandatory for receipt and transmission of messages
	System	proprietary, patented
	Avionics	VHF equipment could be shared with other applications
Source documents		VDL Mode 4 Standards and Recommended Practices (SARPS) Draft, Version 5.4, 21 March 1997; VDL Mode 4 Acceptance Presentation, Helios Technology VDL Mode 4 CNS/ATM applications; Delivering CNS/ATM applications with VDL Mode 4

5.7 Protocols for Passenger Communications

Protocols for providing communication services to passengers are not pertinent to the NAS architecture except to the extent that the protocols facilitate or preclude using the link for ATM or AWIN. Certification requirements already include specifications regarding harmful interference.

Digital television compression techniques (Digital Video Broadcasting [DVB] group standards), broadband Internet, corporate communications, and interactivity are pushing new developments in the space segment entirely dedicated to digital data transfer. Such services are Astrolink (Lockheed Martin), Skybridge (Alcatel), and Galenos (Eutelsat). Multicasting Internet data over satellite (addressing a number of selected end users) becomes a common service. MPEG 4 and Null Packet Optimization (NPO) increase the efficiencies of data transfer.

On the other hand, the satellite industry is affected by heavy competition from the optical fiber network and is pushed out from highly populated areas. Broadcasting and global access will remain the uncontested satellite business area.

5.8 Summary

The communications links are summarized in Table 5.8-1, which presents the key performance characteristics. The most significant consideration in our review has been the need to provide high bandwidth and capacity. As shown, existing and near term links are limited in bandwidth and capacity and will be unable to meet the future traffic load from FIS and TIS. Message latency is also a significant consideration, especially for the ATC critical message types. Considerations such as modulation scheme, frequency, integrity, range and protocol are important design considerations buy are not the major factors for selecting a future data link.

Table 5.8-1. Capacity Provided by Various Communication Links

Comm Link	Bandwidth	System/ Channel Capacity	Channel Data Rate	Message Latency
DSB-AM Voice	25 kHz	Shared bi-directional channels, 118-137 MHz	No data	250 msec.
HF Voice	25 kHz	Shared bi-directional channels, 118-137 MHz	No data	3 minutes
ACARS	25 kHz	Shared bi-directional channels, 118-137 MHz	2.4 kbps	5 seconds, mean plus one sigma
VDL Mode 2	25 kHz	Shared bi-directional channels, 118-137 MHz	31.5 kbps	3.5 seconds, 95%
VDL Mode 3	25 kHz	Four subchannels per 25 kHz	31.5 kbps	250 msec.

Comm Link	Bandwidth	System/ Channel Capacity	Channel Data Rate	Message Latency
		channel, 118-137 MHz		
VDL Mode 4	25 kHz	Shared bi-directional channels, 118-137 MHz	19.2 kbps – 31.5 kbps	250 msec.
VDL – B	25 kHz	Shared bi-directional channels, 118-137 MHz	31.5 kbps	< 3.5 seconds, 95%
Mode-S	2 MHz	Single channel, 1090 MHz	1000 kbps Total, effective rate 300 bps/aircraft[2]	1.2 msec.
UAT	3 MHz	Single channel	1000 kbps	1.2 msec.
GEO Satellite	500 MHz	Hundreds of channels	16 – 2,000 kbps	300 msec propogation
MEO Satellite	30 MHz	24,000 voice circuits	5-6 kbps	100 msec propogation
LEO Satellite		3,840 voice circuits	2.4 – 9.6 kbps	100 msec propogation
HFDL	3 kHz	Two channels per ground station	2.4 kbps	> 5 seconds, mean plus one sigma

5.9 Link Considerations

5.9.1 Ground based systems

All aviation communications systems based on ground stations have limitations of coverage and range. The majority of aviation communications systems are line of sight limited. The radio frequency power available permits operation at distances up to 200 nautical miles (nm)., The curvature of the earth however, blocks the signal to aircraft unless the aircraft is at high altitude. At low altitudes such as 5,000 feet, the line of sight range is reduced to 30 nm. Mountains also block signals and reduce potential coverage. Satellites are much less limited in coverage but do become constrained by available power. A geosynchronous satellite can cover one-third of the earth but the radio frequency power will be far less than for terrestrial systems. Traditionally satellite systems have used dish antennas to increase received power. Newer satellite concepts include low earth orbit (LEO) and medium earth orbit (MEO) systems that are closer to the earth, which improves the available power while reducing the coverage for each satellite.

5.9.2 Frequency band

The aviation industry traditionally has used frequency spectrum allocated specifically to aviation applications and protected by national and international law from interference. Under international agreement, the aviation communications frequencies are limited to ATC and AOC use. Services such as entertainment and passenger communications have been prohibited. All of the VHF systems, voice DSB-AM, ACARS, VDL Mode 2, Mode 3, and Mode 4 are designed to operate within the current 25 kHz channel spacing of the 118 - 137 MHz protected VHF band.

Three major configurations of satellite systems were considered. GEO systems depend on satellites in geosynchronous orbit. Usually a single satellite provides wide area coverage that is essentially constant. Coverage is not possible at the poles. MEO satellites move relative to the earth and their coverage shifts. A number of satellites are needed and earth coverage is virtually complete. A failure of a single satellite causes a short-term outage. LEO satellites move quickly relative to the earth and require numerous satellites for full earth coverage; therefore, an outage of a single satellite is short-term.

[2] RTCA DO-237, Jan 1997

5.9.3 General Satellite Comments

Alternatives to these systems likely will be provided by established service provides, such as Inmarsat, and Boeing, which is aggressively pursuing multimedia to the passenger with asymmetrical return link. There will be a premium charge for this type of system relative to fixed ground terminals, particularly when outside of populated areas.

Boeing already has demonstrated direct video broadcast (DVB) standard communication to the aircraft. The emerging DVB-RCS (return channel satellite) standard probably will be capable of asymmetric communication with aircraft and be available in 2007.

By 2015, EHF (Q/V) band systems operating in the 37.5-40.5 GHz and 47.2-50.2GHz range should be available in addition to Ka-band systems. The EHF systems will have similar capabilities to Ka systems, with greater bandwidth and higher data rates, but more severe rain fade. The following table lists system characteristics based on FCC filings. Most of these EHF systems never will be fielded. None of them are likely until the Ka-band systems are saturated. It is expected at least one EHF System will be available in 2015.

Table 5.9-1. EHF Satellite FCC Filings

Company	System Name	Service Type	Architecture NGSO (No. of planes) GSO (No. of slots)	Communications System		Cost ($B)	Data Rates (Mbps)
				Phased Array Antenna	On-Board Processing		
CAI Satcom	N/A	FSS	1 GSO (1)	No	No	0.3	38
Denali	Pentriad	FSS & BSS	9 HEO (3 at 63.4°)	Yes	No	1.9	10 - 3875
GE Americom	GE*StarPlus	FSS	11 GSO (9)	No	Yes	3.4	1.5-155
Globalstar	GS-40	FSS	80 LEO (10 at 52°)	Yes	No	N/A	2 - 52
Hughes	Expressway	FSS	14 GSO (10)	No	No	3.9	1.5 - 155
Hughes	SpaceCast	BSS	6 GSO (4)	No	No	1.7	0.4 - 155
Hughes	StarLynx	MSS	20 MEO (4 at 55°) 4 GSO (2)	Yes	Yes	2.9	<2 portable <8 vehicle
LEO One USA	Little LEO	MSS	48 LEO (8 at 50°)	No	Yes	0.3	0.032 - 0.256
Lockheed Martin	Q/V-Band System	FSS & BSS	9 GSO (9)	Yes	Yes	4.7	0.384 - 2488
Lockheed Martin	LM-MEO	FSS	32 MEO (4 at 50°)	Yes	Yes	6.82	10.4 - 113.8
Loral	CyberPath	FSS	4 GSO (4)	Yes	Yes	1.2	0.4 - 90
Motorola	M-Star	FSS	72 LEO (12 at 47°)	Yes	No	6.2	2 - 52
OSC	OrbLink	FSS	7 MEO (1 at 0°)	No	No	0.9	10 - 1250
PanAmSat	V-Stream	FSS	12 GSO (11)	No	No	3.5	1.5 - 155

Company	System Name	Service Type	Architecture NGSO (No. of planes) GSO (No. of slots)	Communications System		Cost ($B)	Data Rates (Mbps)
				Phased Array Antenna	On-Board Processing		
Spectrum Astro	Aster	FSS	25 GSO (5)	No	No	2.4	2 - 622
Teledesic	V-Band Supplement	FSS & BSS	72 LEO (6 at 84.7°)	Yes	Yes	1.95	10 -100 up 1000 down
TRW	Global EHF Satellite Network	FSS	15 MEO (3 at 50°) 4 GSO (4)	Yes	Yes	3.4	1.5 - 1555

GSO = Geostationary Orbit, NGSO = Non- Geostationary Orbit, MEO = Medium Earth Orbit, LEO = Low Earth Orbit
BSS = Broadcast Service Satellite, FSS = Fixed Service Satellite, MSS = Mobile Service Satellite
Note that the Cost column numbers are generally artifacts of FCC financial rules, not actual system costs.

Ka and extremely high frequency (EHF) systems are intended for fixed or slowly moving terminals, not for aviation speed terminals (path delay variation, Doppler, frequent hand-off between spot beams). Coding and other link margin features may be used to compensate for fast motion when above atmospheric degradation (rain). The GEO and MEO systems avoid oceans by not pointing spot beams there (systems with phased array antennas will be capable of pointing at oceans) and LEO systems plan to power down the satellites while over the oceans or low population areas. These issues are not technological problems; they are design choices based on business cases. To insure capability for aeronautic use, economic opportunity needs to be communicated to the system developers (business cases supporting premium charges, particularly over unpopulated areas).

6 Ground–Ground Communications

The NAS Ground-Ground Communication Systems Architecture will evolve greatly between 2000 and 2015. Much of the infrastructure needed to support this evolution already is planned within the NAS Architecture, so the 2015 CSA is not likely to raise any new issues for the NAS.

6.1 Distributed Processing

The most significant impact on the NAS architecture is likely to be the transition from local databases to the NAS-wide information system (NWIS), which implements the concepts of flight objects. As envisioned in NAS Architecture V4.0, the flight object is a logical entity in a fully distributed database architecture. The flight object is characterized as a logical entity rather than as a physical entity because it is not necessary for all the data that the flight object comprises to exist in a single physical location.

For example, the flight object might comprise data from the flight plan, additional data assembled within the NAS as the flight progresses, and data that resides at an AOC, such as characteristics of the aircraft, gate assignments, and other information maintained by the aircraft operator. The physical representation of the flight object might contain some data, but also would contain links to other data. Thus, the data values are stored non-redundantly, minimizing the need to synchronize updates.

Use of the flight object to support DAG-TM imposes the requirement on ground systems to be able to assemble a regional or NAS-wide picture of air traffic, including projected movement through the airspace. The controlling facility for an aircraft always will have current location and trajectory information, so it will be able to transmit updates to all other NWIS servers so that every facility has access to current information. NWIS represents a significant increase in the amount of NAS-wide information, but this already is considered in the NAS 4.0 architecture, so it is not an issue.

This database architecture implies a communications architecture in which the FAA is connected to all participating airlines and other participating operators. This type of connectivity will be provided by the FAA Telecommunications Infrastructure (FTI) program and by subsequent upgrades for interfacility communications. Communication between the FAA and AOCs is likely to use ATN-compliant systems, including features for network management and security, that were not included in the first edition of the ICAO Manual for ATN Communications. There will be a need for the ATN to support Subnetwork Dependent Convergence Facilities for other protocols besides ISO/IEC 8208 in order to work with the modern communication network protocols used by FAA and airlines ground systems.

As work on decision support systems progresses, standard formats for data elements must be agreed upon or other techniques must be used to ensure interoperability between the FAA's systems and the various airlines. If source data for the flight object fields are not standardized, the FAA should investigate techniques being developed for electronic commerce, such as the use of the XML protocol, which would allow each AOC to continue to use its own formats.

Weather services will continue to require access of weather databases residing at various locations. To some extent, the ground-ground communication is outside the scope of the NAS since weather service providers may use non-government weather sources and will use commercial communication service providers. Nevertheless, there will continue to be a need for the Air Traffic Control System Command Center and other FAA facilities to have access to weather data. These requirements already are considered for FTI.

6.2 Information Security

The increased connectivity of the NAS communications systems will make it even more important to implement information security measures. Coordination between the FAA and AOCs requires communication. The "Manual of Technical Provisions for the Aeronautical Telecommunication Network," ICAO Document 9705, is being revised to address information security, but this covers only those areas that affect interoperability; i.e., the protocols. Protection of the ground systems is outside the scope of a communications SARPs.

ICAO guidelines (cf. ADPS Manual Part I Chapter 3 Appendix B) recognize the need to "take account of the need to protect the system against unauthorised access and unauthorised transmission" when implementing a data link based system. Whether recognition of this need will translate into programs of work is unknown, but it is quite possible that this topic will be considered as "local matter." The FAA and most AOCs are likely to have strong policies on information security.

Programs to improve public access to FAA weather data, traffic information, congestion data, and other data intended to improve pilots' and travelers' information also will increase the vulnerability of the NAS communication systems to attacks. These are areas for continued research and development.

6.3 Effects of Commercialization

One very significant trend in recent years is the commercialization of service providers, including the handing over of operation of airport and other air navigation facilities and services by governments to autonomous authorities or even to the private sector. Within the NAS, the government has operated most aeronautical communication systems, with oceanic communications (HF and satellite) being a notable exception.

The provision of ATM facilities and services is, under the Chicago Convention, the responsibility of national authorities. The commercialization of such provision therefore necessitates both prescribed delegation of operational functions of governments and changed regulatory functions of governments. The recommended architecture uses broadcast satellites only for non-safety-critical services. Communication services provided by commercial service providers for safety-related communications presumably will require certification, which is an inherently governmental function that is not subject to delegation. With the FTI program, the FAA is increasing its reliance on commercial communication service providers for operation of networks, so it will gain greater understanding of the issues related to the use of commercial service providers.

For both ground-ground and air-ground communication services, the ability to adopt commercial networks for aeronautical use can provide the ability to gain improved performance through the use of new technology. As discussed above, security is becoming increasingly important for aeronautical applications, but progress on ICAO security standards is slow. On the other hand, commercial communication providers serve a market that demands increased security very soon; this increase is needed to implement e-commerce and other applications involving financial transactions or personal privacy, so there is a significant investment in security techniques.

6.4 Infrastructure

Because the current NAS uses only two communication service providers for air-ground communications (ARINC and SITA), and those service providers focus on aeronautical communication, connectivity between the FAA and service providers is well-established and stable.

ATN routing protocols make it possible for ground end systems to communicate to an aircraft without regard to the subnetworks being used as long as all subnetworks are ATN-compliant and have a defined Subnetwork Dependent Convergence Facility (SNDCF). It no longer will be necessary for an automation system to have different communication interfaces depending on whether the data is being transferred via satellite, HFDL, etc.

Satellite broadcasts will not use ATN protocols, since ATN does not yet have provisions for a broadcast capability. Consequently, it will not be possible to use the ATN routers in the NAS networks for access to the broadcast communication providers unless those service providers establish an ATN gateway. It is more likely that the NAS will need to include a TCP/IP (or possibly a proprietary) interface to the communication service provider. Because the ATN routers will not be useable for this interface, it probably will be necessary to implement a gateway between the NAS and the broadcast providers; this would be similar conceptually to the gateways used for access to ACARS networks.

VDL-3 and any other networks with voice capability will be digital and thus require vocoders. If the FAA implements digital voice for interfacility and intrafacility communications, this could lead to potential voice quality problems when air-ground vocoders might be operated in tandem with vocoders existing in other links of an end-to-end communications chain. As each vocoder introduces a deterioration of signal quality, this situation could result in an unacceptable deterioration of the voice signal quality as perceived by end users. This issue has been discussed by ICAO's ATS Voice Switching and Signaling Study Group (AVSSSG) and within the Aeronautical Mobile Communications Panel, but has not been resolved. This issue is discussed in Task 10.

Although the recommended architecture uses satellites only for air-ground communications, there are situations in which satellite communication would be beneficial for ground-ground communications, especially where it is expensive or difficult to provide infrastructure.

In addition, some sparsely populated areas such as Alaska have remote air-ground sites that do not have backup ground-ground connectivity for those events when the primary link fails. In other cases, backup links are available, but these require diverse, hence expensive, leased lines that have very low usage. Satellite services could replace low duty-cycle applications currently served by leased lines, saving landline costs and the hardships of maintenance in remote areas.

The use of satellites (and commercial service providers) helps avoid problems of co-site interference. If VHF broadcast required additional transmission facilities, co-site interference issues might occur if the new transmitters were geographically near other facilities. Use of commercial service providers also is beneficial because it relies on the service providers to build and maintain the ground facilities.

Most communication networks for aeronautical communications have a redundancy requirement to achieve the required availability. For satellite ground-earth stations (GES), there should be ground-ground links to two geographically distant GESs so they would not be affected by the same local atmospheric conditions. This is especially important for satellite systems that are affected by rain attenuation; in this case, one of the GES should be located in an area with below average precipitation.

6.5 Mobile Communication Issues

Mobile communications imposes a requirement to be able to address a specific aircraft using the ICAO 24-bit aircraft identification from anywhere within the NAS. Any ATN-compliant system provides this capability, so it is not an issue.

Until—and unless—there is a convergence of ATN and TCP/IP protocols, there will be a continued need for gateways, protocol converters, or other devices to accommodate multiple protocols. Communications to aircraft, airlines, and other CAAs is likely to use ATN protocols, and intrafacility communication is likely to use TCP/IP. Convergence of the ATN protocols to take advantage of future commercial development in TCP/IP would make it possible to exploit the commercially available systems instead of being required to implement special systems for use only in aviation. Standards work is necessary to define the convergence of the protocols. This work needs to include consideration of the transition issues.

Because the OSI protocols used for the ATN have very few users outside of aviation, most of the research and development is targeted towards TCP/IP. Until there is convergence of ATN to use the commercially popular protocols, additional research is likely to be needed to improve the performance of the ATN. Although ATN routers are designed to be able to support use of satellite links, most of the laboratory work on the ATN has been conducted using terrestrial links. Experience with TCP/IP for satellite communications has uncovered performance issues, some of which already are being researched by NASA. Similar research is needed to identify the performance issues related to the use of the ATN in satellite based networks, to determine the system tuning parameters or other changes to maximize the utility of satellite subnetworks in the ATN.